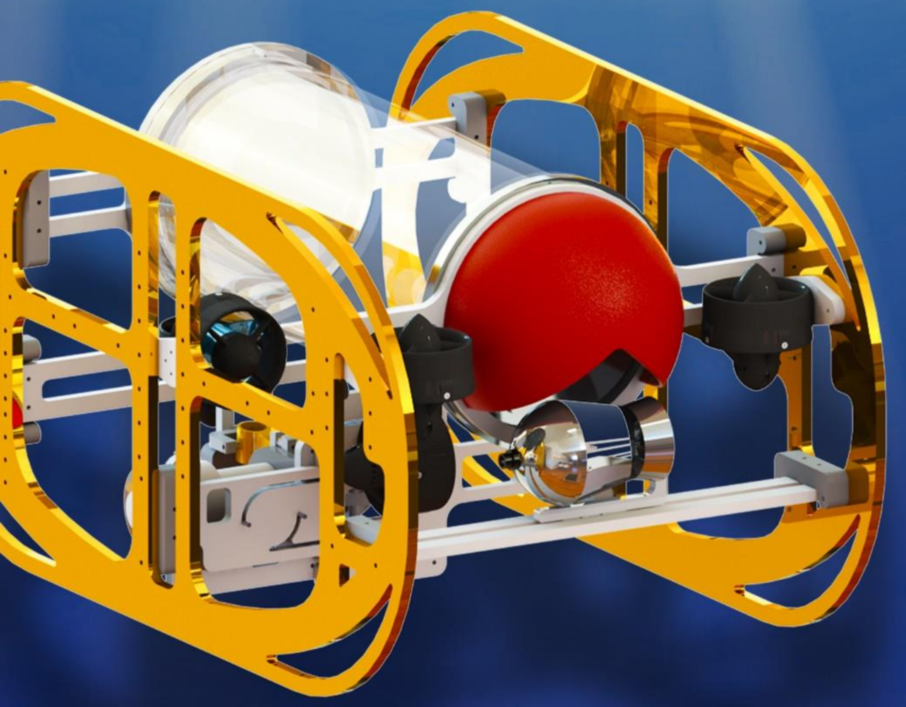
CARETTA CARETTA



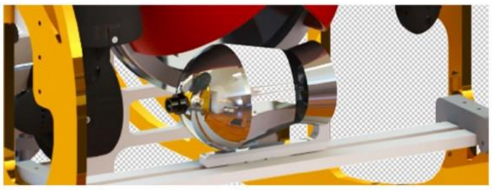
- SEMI AUTONOMOUS
- THRUST FORCE 100N
- RATED DEPTH 50m
- SMART VISION SYSTEM
- MULTIFUNCTION GRIPPER
- ONSHORE WEIGHT 14KG

EMU-CARETTA-01

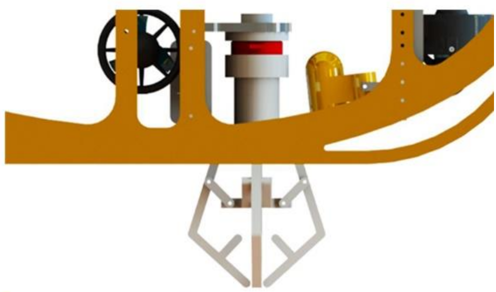
UNMANNED UNDERWATER VEHICLE

THE CARETTA^2 - UUV

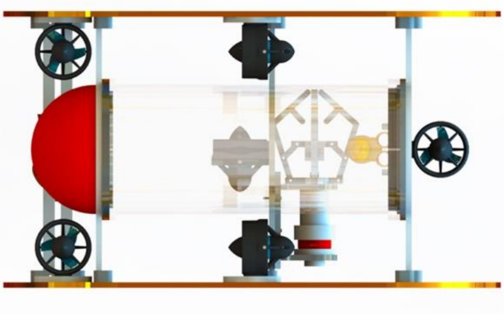
Featuring a compact, modular design, upgradable autonomous capabilities, a custom made gripper, six BlueRobotics T200 thrusters , an HD camera and a 360 camera, caretta is perfect for underwater inspection and scientific research operations. Our specially designed, easy to use software system enables seamless and precise control of the vehicle, allowing it to perform the desired missions in the most efficient way.



360°camera



GRIPPER



The Capstone Team Project

MECT 411

Name of Project: *Unmanned Underwater Vehicle (UUV)*

Group Name: *EMU Aquabotics*

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Semester: *Fall/Spring 2019*

Submission Date: *15th of May 2019*

Eastern Mediterranean University

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ABSTRACT

Unmanned Underwater Vehicles (UUVs) have a wide range of applications in marine geoscience, and are increasingly being used in the scientific, military and commercial sectors. [1] In this project we propose a UUV with the capability of diving to a desired depth, navigating through narrow channels, manipulating, sorting and collecting small objects as well as identifying targets. The proposed design configuration is modular, compact and light weight to perform the mission efficiently and effectively. The body is made entirely of HDPE and fitted together using custom designed 3D printed parts to ease connecting the supports to the main frame. A fixed camera is placed facing downwards, having the gripper and the mission probes in its field of view, while the 360 rotating camera is placed at the front as a pilot camera to maximize our steering field of view. Our custom-made main hull features both mechanical and chemical isolation to ensure the safety of the electrical components enclosed. The topology of the proposed design is optimized to meet the performance requirement. The design configuration is proposed to meet the challenges and mission objectives of the RoboSub international competition. The proposed design has six BlueRobotics thrusters, providing approximately 50 N of thrust each. The modular mechanical and electrical platforms enable the vehicle to switch between AUV and ROV systems efficiently. The batteries provide the power for the main unit of the AUV, the Intel NUC, and the motors are controlled by the PixHawk controller which in turn controls the AUV stability. While the overall objective is to build a vehicle fit to compete in RoboSub 2019, the objective of the capstone team project is to design, manufacture, test and validate Prototype One, ROV CC01, and complete the design process of Prototype Two, AUV CC02, which must meet all the parameters and tested for RoboSub trials. The design is proposed in order to meet the DFC, DFMA and availability constraints.

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LIST OF SYMBOLS and ABBREVIATIONS

Table 0-1Symbols and Abbreviations

1	AHRS	Attitude Heading and Reference System
2	AI	Artificial Intelligence
3	AoI	Area of Interest
4	AUV	Autonomous Underwater Vehicle
5	ROV	Remotely Operated underwater Vehicle
6	Al 6063	6063 Aluminum Alloy
7	HDPE	High-Density Polyethylene
8	CG	Center of mass
9	CB	Center of buoyancy
10	CV	Computer Vision
11	DAQ	Data Acquisition Device
12	DoA	Direction of Arrival
13	DoF	Degrees of Freedom
14	DSP	Digital Signal Processing
15	DVL	Doppler Velocity Logger
16	ESC	Electronic Speed Controller
17	FMEA	Failure Mode and Effects Analysis
18	I/O	Input Output
19	IMU	Inertial Measurement Unit
20	PDB	Power Distribution Board
21	RBG	Red Blue and Green
22	ROS	Robots Operating System
23	ROV	Remotely Operated Vehicle
24	SLAM	Simultaneous Localization and Mapping
25	TDoA	Time Difference of Arrival
26	UUV	Unmanned Underwater vehicle
27	DC	Direct Current

28	AC	Alternating Current
29	FPGA	Field Programmable-Gate Array
30	MUSIC	Multiple Signal Classification
31	ADC	Analog to Digital Converter

Chapter 1 - INTRODUCTION

1.1. Detailed definition of the project

Underwater research has been an interesting field for many decades. The need for underwater vehicles (UUV) can be spotted in different aspects of underwater needs especially discovery and rescue purposes. At the early begging's of underwater vehicles and the development of remotely operated vehicle (ROV), the process was taking too much time to be able just to test underwater. Today with the advanced technology in engineering design and prototyping can enable engineers to speed up the process ten times than before.

Autonomous underwater vehicles (AUV) started appearing in the recent years starting with the ability to perform well described missions with no ability to decide in different situations rather the one programmed for. With the huge development of Artificial Intelligence (AI) the situation become much different in every robotic system not only AUVs, to enable robots to take their own unique decisions under different circumstances, an example of a commercial AUV design is shown in figure 1.1.

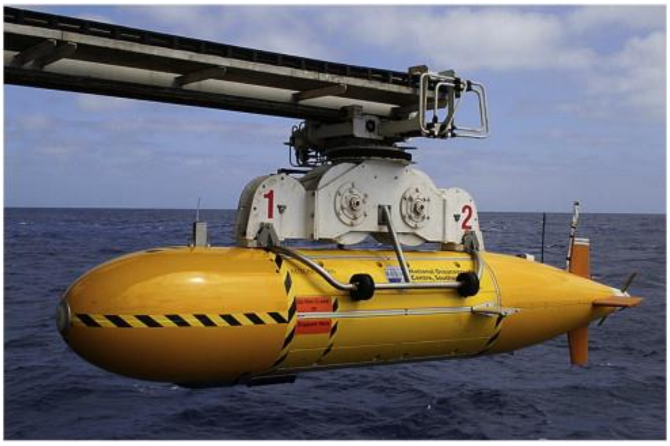


Figure 1-1 UK Natural Environment Council (NERC) Autosub6000 AUV [2]

In a step forward to encourage young people to get more involved in the robotics research, the community of ROBONATION started holding competitions for vehicles development in air, ground and water. ROBOSUB is one of the competitions started in 1997 [3] the main aim from each participated team is to build an underwater vehicle for a certain mission.

Our team's aim is to build an AUV to be able to compete in the ROBOSUB competition 2019 with different challenges to be faced during the development of such complex system. The AUV mainly contain of Mechanical, Electrical and Software subsystems supposed to work together in harmony to accomplish the mission with less error possible.

1.2. Significance of the project

Since the 1970s, underwater vehicles have been widely used in survey and inspection operations, scientific research, military operations, educational outreach and many other applications. An underwater vehicle's main purpose is to reach depths and situations which are difficult, dangerous or impossible for human divers to reach, not to mention the scientific equipment and other tools that it could feature. These vehicles have proved their worthiness in various occasions, such as the 2010 Deepwater Horizon oil spill in the Gulf of Mexico and the 2012 Costa Concordia ship disaster, and (figure 1.2) shows an example of an ROV during its operation. [4] [5]

Figure 1-2 Commercial ROV

There are various classifications and configurations of underwater vehicles:

Table 1-1 Classification of ROVs [5]

Class	Feature	Depth rating (m)	Power
Micro	Low cost small ROV	< 100	<5
Mini	Small, used for observation	< 300	<10
General	Light survey applications	< 200	<100
Inspection	Data collection and object manipulation	< 3000	<25
Light Work	Complex manipulator	< 3000	<100
Heavy Work	At least 2 manipulators	>3000	<120
Trenching and Burial	Capable of carrying heavy objects	>3000	-
AUV	Autonomous untethered vehicles	-	-

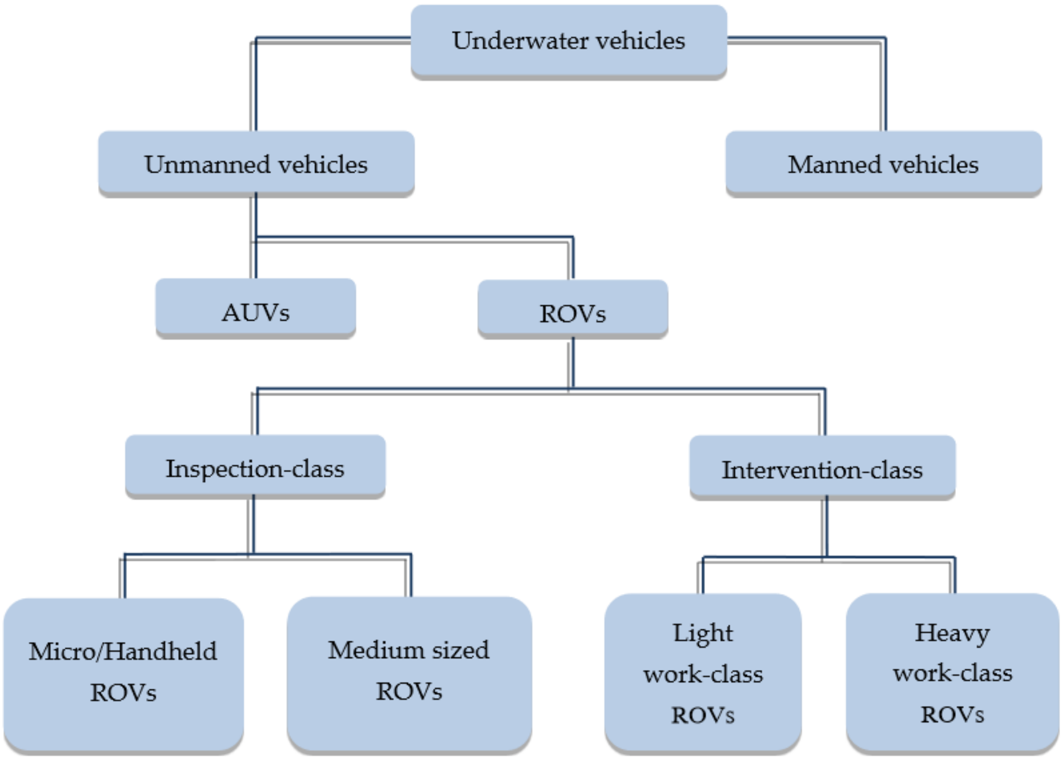


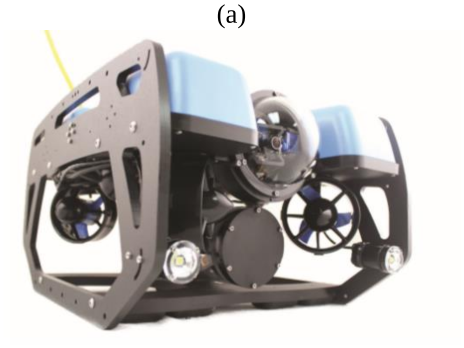
Figure 1-3 Outline of underwater vehicles [6]

ROV Configurations: [7]

- Open or Box Frame ROVs (figure 1-4 (a), (c) and (d))
- Torpedo Shaped ROVs (figure 1-4 (b))

(a)

(b)



(c)

(d)

Figure 1-4 Various ROV Configurations

1.3. Project Objectives

The main objective of the capstone team project is to design, manufacture, test and validate Prototype One, ROV CC01, and complete the design process of Prototype Two, AUV CC02.

1.3.1. Phase 1 Prototype One ROV CC01

a. Comply with all size, weight, buoyancy, and safety requirements of the ROBOSUB competition.
b. Modular for future expandability and relatively lightweight while being able to protect the fragile components within
c. Go to a depth and maintain that depth
d. Gripper capable of grasping and manipulating small objects
e. Cameras for vision and navigation purposes

The completion of prototype 1 is the main objective of this phase, scheduled for completion by the end of May, 2019.

1.3.2. Phase 2 Prototype Two AUV CC02

a. Recognize a color and track a path
b. Navigate through the competition start gate and complete at least one competition task
c. Torpedo shooting mechanism
d. Sonar localization system capable of identifying and locating an acoustic signal underwater.
e. Operate for 15 minutes using internal battery

The purpose of phase 2 is to complete prototype 2 which must meet all the parameters and tested for RoboSub trials. Scheduled for completion by the end of June, 2019.

The UUV will be either remotely operated using a tether interface connected to a computer on the surface, or ideally the UUV will be autonomous, being controlled by the onboard computer using a state machine and a computer vision algorithm, depending on inputs from the onboard sensors and cameras, although autonomy may not be achieved due to time and cost limitations.

1.4. Project Constraints

1.4.1. Cost

The largest constraint on the project design is cost, due to the limited budget of the team and the large size and scope of the project the cost will naturally be high, therefor to be able to complete the project the cheapest suitable option will almost always be chosen if possible.

1.4.2. Availability & Manufacturability

Availability & Manufacturability are also a major constraint on the design because of limited access to manufacturing facilities in Cyprus, and difficulty importing parts from outside of Cyprus.

1.4.3. Time

The size and scope of the project are extremely large when compared to the time available, there for the project will be done on a very tight schedule, to meet this schedule all appropriate time saving measures will be used.

1.4.4. RoboSub Design Constraints

The UUV will be designed according to the rules and regulations specified by the ROBOSUB annual competition, the ROBOSUB rules were chosen as a basis for the design since the competition was designed to resemble real life applications for UUV's, a list of all the constraints and requirements specified is provided in table 1-2:

Table 1-2 Technical Constraints [2]

No.	Constraint Name	Unit	Max Value
		Mechanical	
1	Mass	kg	38
2	Height	m	0.91
3	Width	m	0.91
4	Length	m	1.83
5	Torpedo Weight	g	900
6	Torpedo Height	cm	5.1
7	Torpedo Width	cm	5.1
8	Torpedo Length	cm	15.2
		Electrical	
9	DC Voltage	V	60
10	Operating time	max	15

1.5. Report Organization

This report has more four chapters and the scheme of each chapter will be shown in this section.

In **chapter 2** background information and some of the term's clarification is discussed before we go any further. In addition, some set of the concurrent solutions to each subsystem and the comparison between each solution is shown. Plus, some ideas about the standards of these solution which allows the reader to understand why the team has chosen the proposed design are provided.

In **chapter 3** the proposed design of the project for each subsystem and the details of each design are provided. In addition, the standards followed by each design is shown so that it will be clear that each subsystem has chosen the right design. The design calculations of each subsystem will be also discussed in this chapter. Finally, the cost analysis of each subsystem will be appearing at the end of this chapter.

In **chapter 4** the manufacturing procedure and how the parts proposed in chapter 3 will be available and what machines will be used to produce the final vehicle are discussed. Plus, a detailed structure of the manufacturing process is provided.

In **chapter 5** the plan objectives of the project and the discussion of the plan that will be applied using the engineering standards stated are provided. Moreover, the two tests which are the onboard test and the off-board test are shown as a scheme and how we are going to apply them, and which test will be applied for each subsystem.

and the off-board test will be shown as a scheme and how we are going to apply them, and which test will be applied for each subsystem.

In **chapter 6** the future work of the team members and the development of the subsystems to be done in the future to enhance the vehicle's performance and functionality will be stated.

Chapter 2 - LITERATURE REVIEW

2.1 Background information

AUVs have been widely used in different fields, so a lot of underwater vehicles manufacturers such as Atlas Elektronik, BAE Systems, BaltRobotics Sp.z.o.o, Boston Engineering Corporation and Kongsberg designed and manufactured AUVs of different classes and configurations. However, as our goal is to compete in the ROBOSUB Competitions, we decided to check the previous designs of other contestants.

Figure 2-1 Various AUVs

ROVs/AUVs are unoccupied, highly maneuverable, and operated by a crew either aboard a vessel/floating platform or on proximate land. Most ROVs are equipped with at least a video camera and lights. Additional equipment is commonly added to expand the vehicle's capabilities. These may include sonars, a still camera and a manipulator or cutting arm. [8]

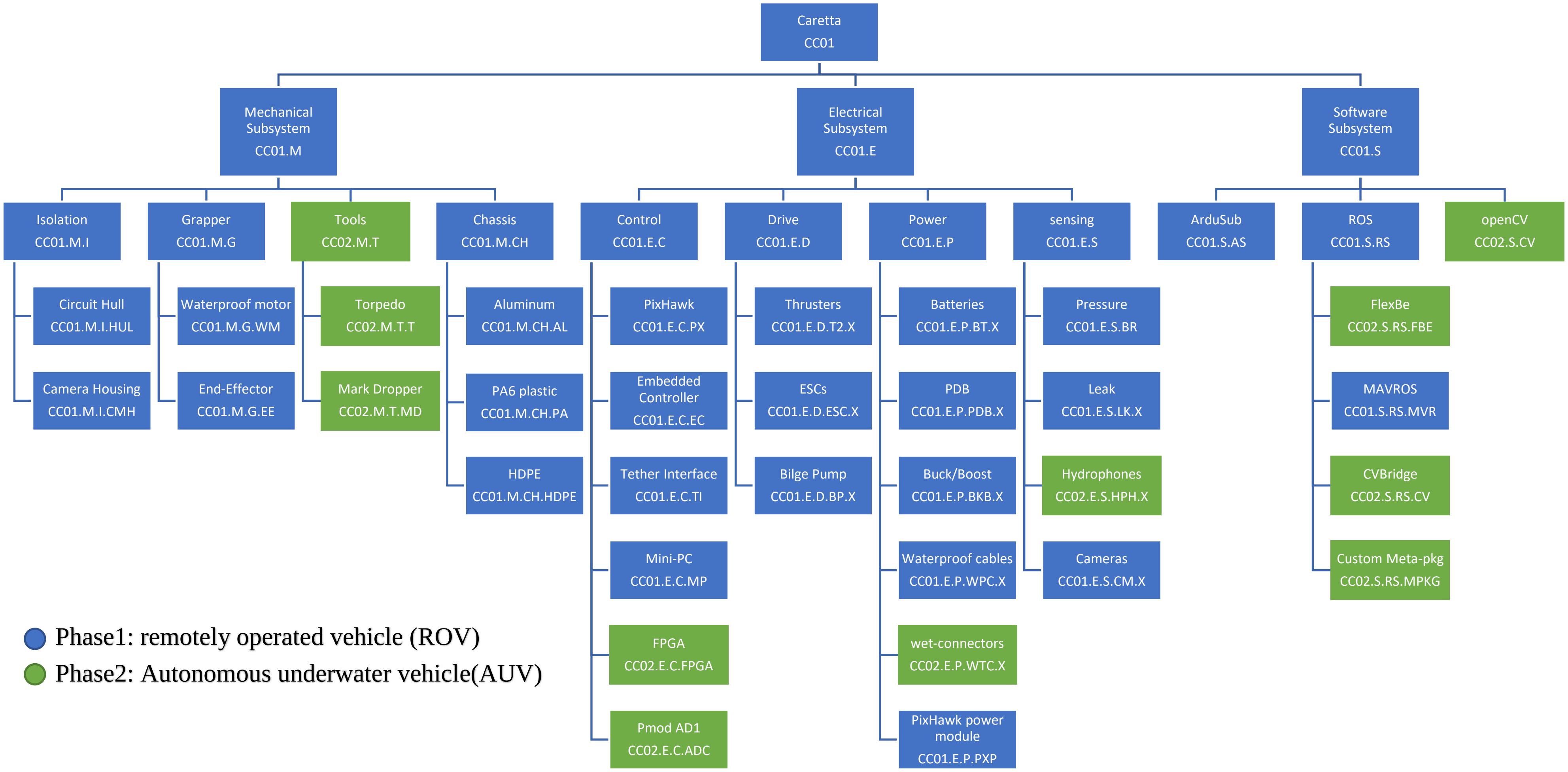


Figure 2-2 Project Breakdown Structure

A. Frame:

The frame of the ROV provides a firm platform for mounting, or attaching, the necessary mechanical, electrical, and propulsion components. This includes special tooling/instruments such as sonar, cameras, lighting, manipulator, scientific sensor, and sampling equipment. ROV frames have been made of materials ranging from plastic composites to aluminum tubing. In general, the materials used are chosen to give the maximum strength with the minimum weight. Since weight must be offset with buoyancy, this is critical. [9]

The ROV frame must also comply with regulations concerning load and lift path strength. The size of the frame is dependent upon the following criteria:

a) Weight of the complete ROV unit in air
b) Volume of the onboard equipment
c) Volume of the sensors and tooling
d) Volume of the buoyancy
e) Load-bearing criteria of the frame.

B. Propulsion and Thrust:

The propulsion system significantly impacts the vehicle design. The type of thrusters, their configuration, and the power source to drive them usually take priority over many of the other components. ROV propulsion systems come in three different types: Electrical, hydraulic, and ducted jet propulsion. These different types have been developed to suit the size of vehicle and anticipated type of work. In some cases, the actual location of the work task has dictated the type of propulsion used. [9]

C. Buoyancy:

Archimedes' principle states: An object immersed in a fluid experiences a buoyant force that is equal in magnitude to the force of gravity on the displaced fluid. Thus, the objective of underwater vehicle flotation systems is to counteract the negative buoyancy effect of heavier than water materials on the submersible (frame, pressure housings, etc.) with lighter than water materials; A near neutrally buoyant state is the goal. [9]

D. Electrical system:

The vehicles power can be supplied from either an on-shore tether connected to a power supply or an on-board battery system. The electrical power is distributed to the main components, including the control unit, such as a microprocessor or a mini-PC, motor drivers, cameras, gripper and other tools.

E. Control system:

The control system controls the different functions of the ROV/AUV, from controlling the propulsion system to switching of the light(s) and video camera(s). From simple relay control systems in the past to today's digital fiber optics and advanced processors, these systems are equipped with a computer and subsystem control interface. The control system has to manage the input from the operator at the surface and convert it into actions subsea. The data required by the operator on the surface to accurately determine the position in the water is collected by sensors (sonar and acoustic positioning) and transmitted to the operator. [10]

Our aim is to build a box frame, mini class remotely operated underwater vehicle (ROV) with some inspection class capabilities to compete at the RoboSub competition. A box frame underwater vehicle consists of an open frame where all the operational sensors, thrusters, robotic arm and mechanical components are enclosed. We chose this configuration over torpedo shaped underwater vehicles as it has significant control limitations. Another reason to choose the open box frame is because it is more spacious and performs better at low speeds, which makes it the obvious choice as the mission requires a lot of tight maneuvers and precise movements. [11]

Next, our objective is to convert this ROV into an Autonomous Underwater Vehicle (AUV). The main difference is that an AUV conducts its survey mission without operator intervention as it is pre-programmed to perform the given task and resurface to a specified point. This presents a challenge for our team as until relatively recently, AUVs have been used for a limited number of tasks dictated by the technology available. [12]

We plan to design a robot capable of housing all the electrical components and payload tools needed in the most efficient way possible, taking all mechanical aspects into consideration, such as size, weight, thrusters, mass distribution and isolation.

Featuring 6 Blue Robotics Thrusters, producing approximately 50N of thrust each, a fixed camera, a High-Definition rotating camera, an efficient gripper, 2 torpedoes, 4 Hydrophone sensor and a Sound Navigation and Ranging (SONAR) system, our 5-member team aims to design and manufacture not only an extremely compact and light weight underwater vehicle, but also one made precisely to perform the mission in the most efficient and time saving method.

2.1.1. Mechanical Subsystem

2.1.1.1. Main frame

Our UUV consists of two main side frames, which are connected by Al 6063 and HDPE (High-Density-Polyethylene) supports which are also used to mount the main components of the vehicle. These components will be fastened together in using bolts and nuts. The main hull is mounted using custom made parts, designed according to the hull's size. Our aim is to reduce the interspaces between components and optimize the side frame to reduce the overall weight of the vehicle, which increase our bonus points in the competition. We use SolidWorks to build a CAD model for the vehicle which enables us to know the exact mass, volume, center of mass and center of buoyancy locations.

There are different configurations for the frame (will be discussed in detail in chapter 3). We compared the most popular and efficient configurations that suits our mission in the following matrix.

Table 2-1 Chassis configurations Pugh's matrix

	Stability	**Durability**	**Ease of assembly**	**Modularity**	**Score**
Priority	4	3	1	2	
2 side frames, attached together by horizontal supports	10 (40)	9 (27)	8 (8)	10 (20)	95
Base and cover, with vertical supports	8 (32)	10 (30)	10 (10)	8 (16)	88
Torpedo shaped	4 (16)	7 (21)	5 (5)	5 (10)	52
Motors attached to the main hull	6 (24)	5 (15)	7 (7)	7 (14)	60

2.1.1.2. Material selection

After careful research, we concluded that HDPE and Al 6063 are the most convenient materials to use as demonstrated in the following Pugh's criteria matrix.

Table 2-2 Material Selection Pugh's matrix

	Cost	**Weight (according to different thicknesses)**	**Availability**	**Durability**	**Manufacturability**	**Score**
Priority	4	2	5	2	3	
Titanium	5 (20)	10 (20)	5 (25)	10 (20)	5 (15)	100
Al 6063	7 (28)	9 (18)	10 (50)	8 (16)	8 (24)	136
HDPE	10 (40)	8 (16)	8 (40)	7 (14)	10 (30)	140
ABS Plastic	8 (32)	7 (14)	7 (35)	5 (10)	6 (18)	109

2.1.1.3. Motor selection

Our main propulsion system depends on six thrusters configured to give us all possible DoFs, which will be explained in detail in the design section. Our selection was made using the following Pugh's criteria matrix.

Table 2-3 Thruster Comparison Pugh's matrix

	Cost	Thrust	Availability	Dimensions	Score
Priority	3	2	4	1	
BlueRobotics T200	10 (30)	7 (14)	10 (40)	10 (10)	94
Seabotix BTD-150	6 (18)	8 (16)	7 (28)	8 (8)	70
Videoray Pro 4	4 (12)	10 (20)	7 (28)	6 (6)	66

2.1.1.4. Main hull and isolation

One of the main challenges in building the AUV is manufacturing a watertight enclosure (isolation tube) capable of withstanding decent depths. During the design and manufacturing process we must be sure that water will not enter the isolation tube.

Our custom-made isolation tube consists of 3 main parts, a tube and 2 caps. The tube and one of the caps are manufactured from PA type 6 plastic due to the ease of its fabrication, the other cap, as heat dissipation is taken into consideration, is made of Al 6063 as it is a good conductor of heat. Our thorough isolation process consists of a two-stage mechanical isolation using O-rings and a three-stage chemical isolation. We chose the isolation technique using the following Pugh's criteria matrix.

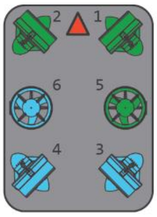
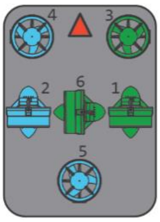
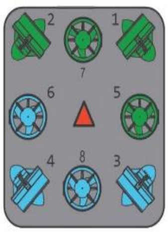
Table 2-4 Various isolation techniques

	Performance	Availability	Manufacturability	Cost	Score
Priority	2	3	4	1	
Threaded end cap and PA6 tube	10 (20)	4 (12)	6 (24)	6 (6)	62
O-ring interference fit with PVC tube	7 (14)	10 (30)	10 (40)	8 (8)	92
O-ring interference fit with Acrylic tube	7 (14)	7 (21)	10 (40)	10 (10)	85

2.1.1.5. Motor configuration

Our motor configuration choice is essential, as we want to acquire all possible degrees of freedom (surge, sway, yaw, heave, roll and pitch) with the six available motors without sacrificing the thrust power. Also, the motors' control depends on the ARDUSUB software, so we want to match our configuration with the software to obtain maximum controllability. We chose our motor configuration after performing the following Pugh's matrix comparison.

Table 2-5 Motor configuration comparison

	Motor availability	**DoFs**	**Controllability**	**Surge Thrust**	**Heave Thrust**	**Score**
Priority	5	3	4	2	1	
	10 (50)	7 (21)	10 (40)	10 (20)	5 (5)	136
	10 (50)	10 (30)	10 (40)	7 (14)	7 (7)	141
	5 (25)	10 (30)	6 (24)	10 (20)	10 (10)	109

2.1.1.6. Buoyancy and stability [13]

This year's mission requires a great deal of stability to ease maneuvering the ROV among the mission probes. As a result, one of our design team's top considerations was to place buoyant components (isolation tube and lights) at the top and heavy components (thrusters and manipulator) at the bottom. This provides a descent separation between the center of gravity and the center of buoyancy, hence efficiently controlling the force couple created and subsequently stabilizing the ROV.

2.1.1.7. Computational fluid dynamics (CFD)

Computational fluid dynamics (CFD) is a very important part of every project since it saves a lot of money and time, it's not always correct and sometimes it's far away from the truth but at least it guides you to the beginning of the road and maybe part of the truth, ANSYS is one of the most famous simulation programs, we are using ANSYS flow fluent which is used for dynamic simulation. Adding the parameters and the working circumstances to the software to get the desired answer. We use ANSYS to get the drag force and lift force to calibrate motors to sustain those forces automatically and have a stable travel underwater. We have done CFD on ANSYS fluid which will be shown in the analysis chapter.

2.1.1.8. Torpedo launcher

Torpedoes are usually fired underwater in different sizes from different AUV's from mini AUV's to the huge submarines and used in wars and hitting targets underwater, any underwater vehicle have a shooting system with torpedoes

Firing a torpedo underwater is one of the requirements of the AUV according to the ROBOSUB standards for AUV's. We have found that a loaded spring mechanism would be the easiest solution for firing underwater since it doesn't require isolation and can travel to a good distance with a controlled distance depending on Hooke's law (equation 2.1).

$$k = \frac{f}{x} \tag{2.1}$$

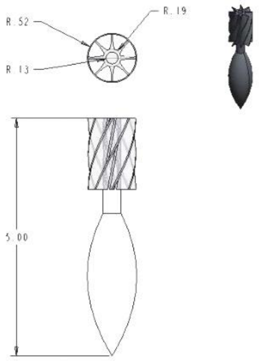
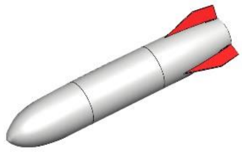
Where k is the spring stiffens constant, f is the force, and x is the deformation of the spring

with adding drag and lift forces to the (F), so the parameters can be modified, this was found to be an effective way more than others team which used pneumatics which requires a lot of isolation and an air tank in which buoyancy will be affected, table 2.1 shows a comparison of multiple torpedo designs.

Other way of firing torpedoes is to use an air tank with an air valve shown in (figure 2.1) which depends on the compressed air to fire the torpedo, although it has some advantages in weight rather than the spring but it has a disadvantage in isolation, both of them are effective ways for shooting torpedoes, we have gone for the easier in isolation, the loaded spring.

The following table illustrates different torpedo designs:

Table 2-6 Torpedo configuration comparison

Team name	Weight (gm)	Length (mm)	Diameter (mm)	photo
Montana	NA	127	13.20	
Zeabus	NA	NA	NA	
CARETTA (proposed)	50	100	27 with fins 17 without fins	

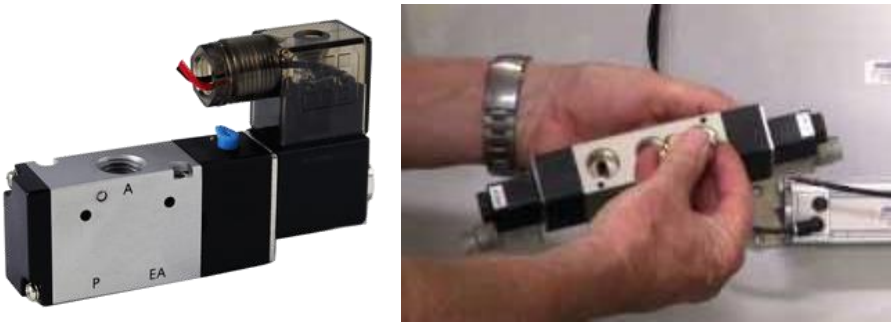


Figure 2-3 Air control valve 3-way two position

2.1.2. Electrical Subsystem

In the electrical sub-system, we will divide it into systems and discuss the alternatives of the circuit elements.

2.1.2.1 Sonar system:

Sonar system is challenging and hard to reach the required result. By studying various papers and journals and reports for various related projects we found that the implementation of a sonar system requires a lot of circuit and signal processing.

To start we shall understand the elements that should be there in a sonar system. And the first element to be used is the hydrophones (figure 2.2) which they are basically a microphone to be used underwater, a hydrophone detects acoustic signals under the water. Most hydrophones are based on a special property of certain ceramics that produces a small electrical current when subjected to changes in underwater pressure. When submerged in the ocean, a ceramic hydrophone produces small-voltage signals over a wide range of frequencies as it is exposed to underwater sounds emanating from any direction.

Figure 2-4 Teledyne marine RESON TC 4013 – hydrophone

Since the we are getting a micro-volt signal from hydrophone, we will need to amplify the signal to be useful and readable by other elements in the circuit. After getting the signal we will need a filter to cut out the unnecessary frequencies. The signal coming out of the hydrophones is an analog signal so in order to process it in a pc we will need to digitalize it using and ADC with an appropriate sampling rate, getting a digitalized signal is the end of the circuit part and will be transferred to a software algorithm to extract the required information from the signal using the estimation process of DoA and TDoA.

Such process can be done in different ways, the two possible ways we found by research in past different developed systems are as following:

a) The use of a DAQ device (figure 2.3)
b) The use of an ordinary DSP board or an FPGA Development board

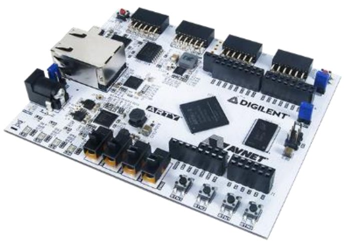


Figure 2-5 Arty A7 Development Board [14]

Figure 2.5 shows the possible board to be used for the sonar system. This board features a powerful complex computation at high speed with clock frequency of 100 MHz. In addition, a DSP slices is integrated on the Artix-7 FPGA included in this development board.

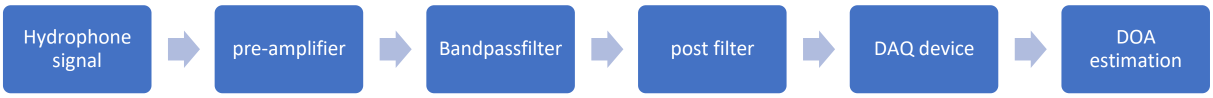


Figure 2-6 Estimating the DOA from an acoustic signal using sonar system implemented [13]

2.1.2.2 Pressure Sensor:

To determine the depth of the vehicle at any moment we will need a pressure sensor. There is wide number of options in the market for such sensor and we have gone through most of the sensors used in similar projects and pick the right option for our own criteria, which mainly is availability, cost and ease of integration with ROS

Table 2-7 summarize the study for various depth sensors to be considered

Table 2-7 Alternatives for Pressure Sensors

Vendor	Model	Depth range	Accuracy	Communication Interface
ASHCROFT	K1,Pressure Transducer	Vacuum to 20,000 psi	±0.50% or ±1.00% span	I2C
TE-Connectivity	MS5803	10 – 1300 mbar	-1.5 to +1.5 mbar	I2C
TE-Connectivity	US300	0 – 15 to 5000 psi	±0.1% Accuracy	I2C
Blue Robotics	BAR30	From 0-30 bar	+/- 400 mbar (408 cm in freshwater)	I2C

OMEGA Engineering	PX319	-15 to 50 psi	±0.25%	I2C

Here we are comparing between various options for the pressure sensor and all the above are nearly the same in terms of range and accuracy. What we are really concerned about is the interface to be compatible with our controlling units and be able to receive values from the sensor easily.

2.1.2.3 AHRS unit:

One of the essential electrical system in Any vehicle is the Attitude heading and reference system (AHRS) to control each degree of freedom and provide stability for the vehicle accurate heading. In market there is a lot of alternatives to be used in a such system, table 2-8 summarize the studied alternatives to be considered for our vehicle.

Table 2-8 Comparisons for AHRS units

Vendor	Model	Pros	Cons
PNI	TRAX AHRS	a. Full AHRS system with 9 axes b. USB interface c. Low power consumption d. Multiple field calibration options	a. 80 pages solution manual b. No programming library or a ROS driver c. Need some type of filtration
InvenSense	MPU6050	a. 6 axis Accelerometer and Gyro b. Lot of resources c. I2C interface	a. No Magnetometer b. Long process to calibrate
Vector NAV	Vector Nav VN-100	a. Very small size 24 x 22 x 3 mm b. Extremely light 3.5 g c. ±2000°/sec Gyroscope Range	a. Long process to integrate b. Expensive
Loar microstrain	3DM-GX4-25	a. High resolution b. direct and computed AHRS outputs in a small package c. Easy integration via comprehensive SDK	a. Quite expensive b. Massive documentation
Xsense	MTi-3 AHRS	a. Available ROS driver b. Easy to interface c. Good documentation a. I2C, SPI, UART RS232, USB b. Very good customer support	a. Very Expensive
PX4	PixHawk	a. Available ROS driver b. Lot of resources c. Excellent documentation d. Lot of built-in features e. Direct ESC interface f. Easy to calibrate g. Pre-written software controllers	a. Integrated only with specific firmware b. Different communication protocol the MAVLink
Sparkfun	Razor 9DOF	a. New MPU-9250 Arduino library with support for the chip's digital motion processing capabilities	a. Controllers to be written for each degree of freedom

	b. Arduino-programmable via USB c. Integrated MPU-9250 IMU and SAMD21 microprocessor d. Very cheap	b. Hard calibration procedure

Our choosing criteria for the AHRS unit are to be compatible with our main control unit and preferred to be connected using USB since we will use mini PC and our main control unit, also to be easy to calibrate for vehicle systems and is better if there is ROS driver for it so we can integrate it easily.

These criteria met in two the Xsense MTI-3 and PixHawk both have pre-written ROS driver and connects using USB, but we had to choose one for our system which mostly will be the PixHawk which is cheaper and pre-written controllers is available.

2.1.2.4 Main Control unit:

In our vehicle a good amount of processing power is required for computer vision and manage the main software which will be possibly developed on top of ROS as discussed in the software subsystem, since ROS is working on a Linux machine, so we will need an appropriate control unit to be able to install the Linux Ubuntu on it.

There much alternatives to be used in such case but the need of various USB ports as well as an Ethernet connection is essential, so our options can be limited to the following boards shown in table 2-4 below.

Table 2-9 Alternatives for mini PCs

Vendor	Model	Pros	Cons
Intel	NUC board	Assembled with intel processor Easy to install Linux operating system 4 USB ports (2 USB 2.0 and 2 USB 3.0) Easy shipping and customer support	-
Axiomtek	MANO882	2 DDR3-1333/1600 SO-DIMM, up to 16GB 4-IN & 4-OUT Digitak I/O 2 Ethernet ports	Processor to be purchased separately Expensive without processor
GigaByte	GB-BRi3H-8130	Cheap 4 USB ports (2 USB 2.0 and 2 USB 3.0)	-

2.1.2.5 Cameras:

The available options for cameras to be installed on the UUV can be divided based on three criteria:

a. Connection method: USB, Wi-Fi or HDMI
b. Isolation: Pre-isolated, or Added-isolation during manufacturing
c. Stereo Vision Availability: Stereo camera, or Mono camera

Although many connection methods are available the most commonly used, is USB connection due to its wide availability, reliability, and ease of use, unlike for example Wi-Fi connection which cause many problems due to poor connection quality underwater and difficulty using multiple cameras at once which is necessary for the intended purpose of the UUV [15], another option is HDMI although it's as reliable and easy to use as USB it still has a significant disadvantage in cost compared to USB.

The second criteria is stereo vision which is a very useful feature since stereo cameras can give "Depth Map" information alongside the RGB footage, but this feature comes at a significant cost of at least 449$ per camera [16], while a good quality mono camera although lacking depth maps it will cost around 50-100$, but it will require a software method to obtain depth information.

As to the final criteria isolation (waterproofing), the two options are either pre-isolated cameras or added-isolation during manufacturing, which boils down to a tradeoff between cost and manufacturing time and effort, pre-isolated cameras will cost more while adding isolation will take extra manufacturing effort.

2.1.2.6 Power System

The power system will talk about the amount of voltage and current delivered to each device and board and try to control them by using some specific boards that perform the voltage regulating and current limiting processes. These terms can be done using a voltage regulator or a converter that steps up or down the voltage and the current. The specifications of each device must be considered so that no over current or voltage will be applied.

After we have done the research on this topic, we found that we have 3 different types of converters and they are more convenient for us because it provides an adjustable voltage or current feature.

a) **The buck converter (Figure2.4):** is used for stepping down the input voltage to a minimum value but not being higher than the input and it uses a constant current. (Note that the circuit diagram is general and the one shown on the left has more safety and calibration features).

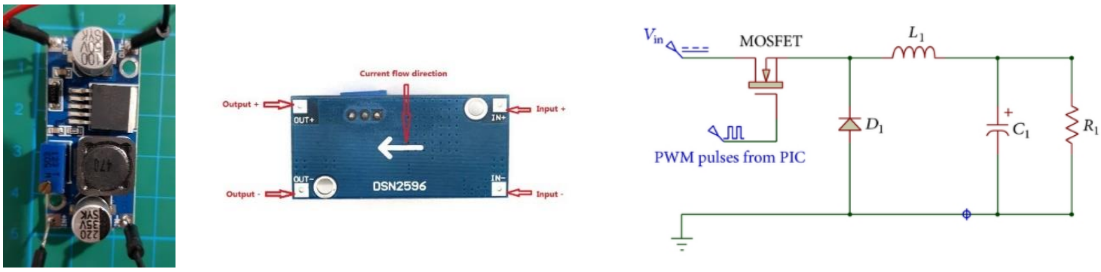


Figure 2-7 Buck Converter and its circuit diagram [17]

b) **The boost converter** (Figure2.5**):** which does the opposite that the buck converter does which is stepping up the input voltage to a maximum value and again at a constant current. (Note that the circuit diagram is general and the one shown on the left has more safety and calibration features).

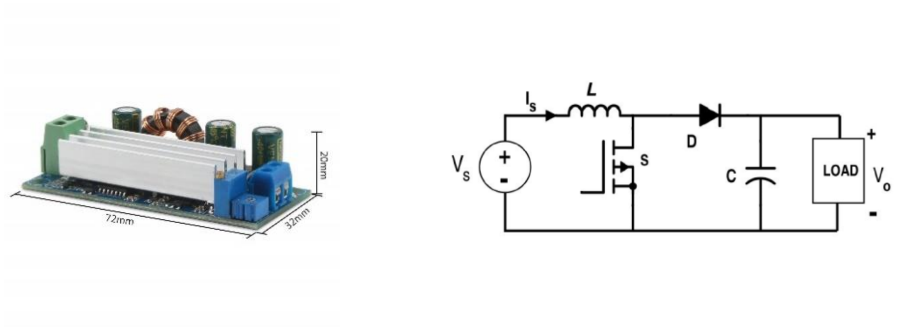


Figure 2-8 Boost Converter and its circuit diagram [18]

c) **The buck/boost converter** (Figure 2.6)**:** it combines the functionality of both the buck and the boost converters as it steps up or down the voltage, some of these converters are with a constant current and some with an adjustable current feature which is the thing we want. (Note that the circuit diagram is general and the one shown on the left has more safety and calibration features).

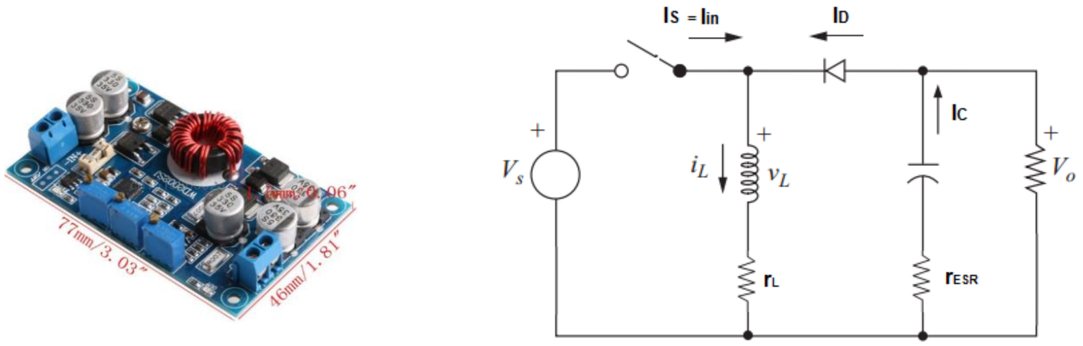


Figure 2-9 Buck/Boost Converter and its circuit diagram [19]

d) **Voltage regulator** (Figure 2.7)**:** this type of regulators uses a MOSFET transistor which can be heated so fast and whenever it heats up it turns itself off till it cools down and that what we don't want. (Note that the circuit diagram is general and the one shown on the left has more safety and calibration features).

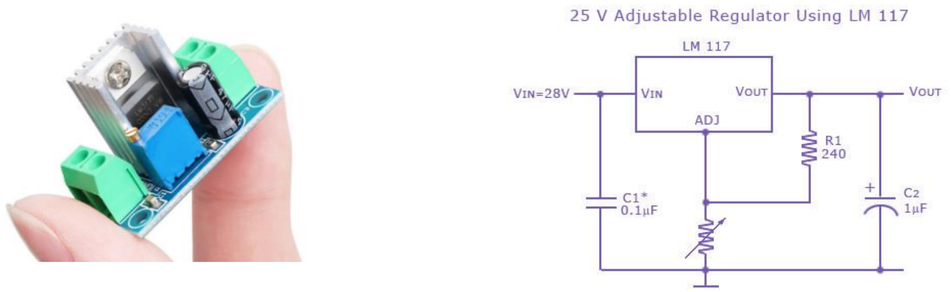


Figure 2-10 Voltage Regulator and its Circuit Diagram [50]

e) **Programmable converters** (Figure 2.8)**:** so, it makes the regulation precise to have that exact output voltage and most probably we will be using the programmable one because it is better for us to have a precise value not to damage our devices.

Figure 2-11 Intelligent Programmable Converter [20]

2.1.2.7 Motors

The Electronic Speed Controller (ESC): should be used to give a Pulse Width Modulation (PWM) signal to control the speed of the motor. Deliver the desired power to the motor whenever needed (asked for by the control unit) and to provide a safety for the over current applied to it.

The basic **ESC BlueRobotics** (Figure 2.9) seems to be the best choice to use together with the T200 BlueRobotics thruster since it can be controlled by the unit we have. However, there are plenty of these ESCs out there and you can create a custom one, but this will be a time consuming where you can use that time focusing on something else. (Note that the circuit diagram is general and the one shown on the left has more safety and calibration features).

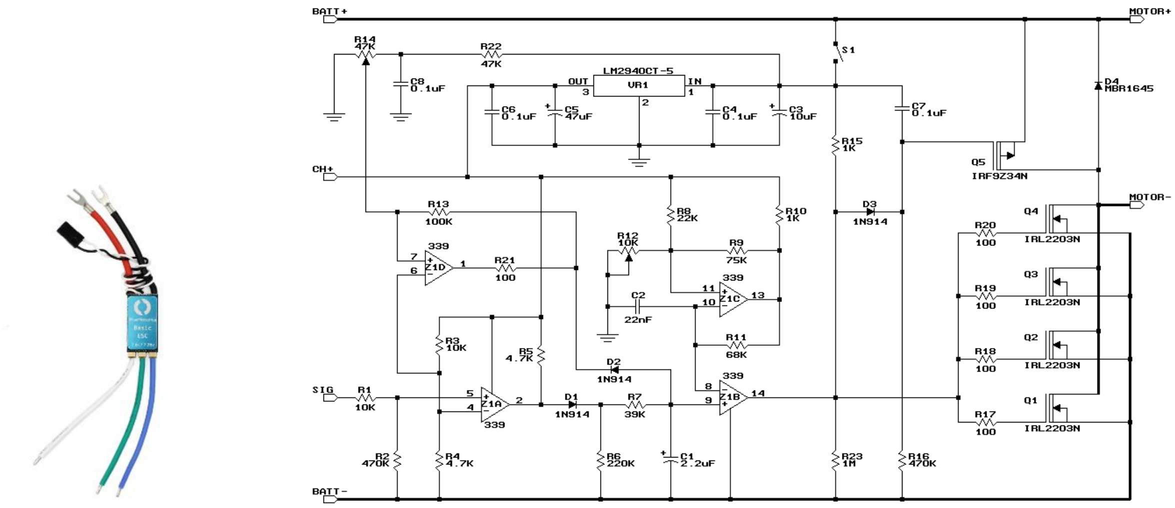


Figure 2-12 Basic ESC BlueRobotics and its Circuit Diagram [21]

2.1.2.8 Monitoring

- **The leak detection sensor: SOS BlueRobotics** (Figure 2.10) will interrupt the system and sends an alarm to the controller whenever the water touches the probes connected to it meaning that there is a leakage in the system and it may cause major problems.

We need such a sensor since we are going to use an isolated tube that has an opening from one side to have all the connections coming out and going to the devices outside that tube and whenever the water goes in then the whole system will be damaged.

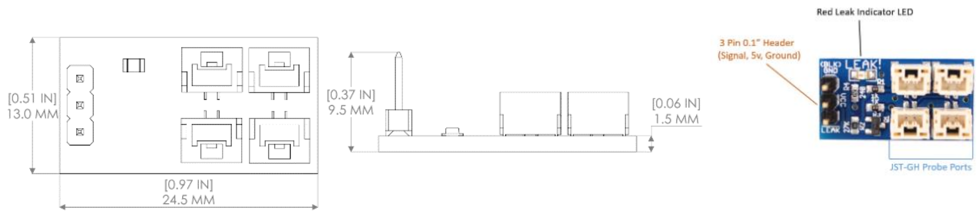


Figure 2-13 SOS Leak Sensor BlueRobotics

- **f) Battery monitoring system** (Figure 2.11)**:** which will be monitoring the voltage rating of each cell and the overall cells, so it allows the team to know when to charge the battery.

Figure 2-14 Li-Po Voltage Checker [22]

- **g) Weather sensor** (Figure 2.12)**: DHT11** sensor will allow the team to check the temperature and the relative humidity of the enclosure to try to control them not to affect the efficiency of the devices.

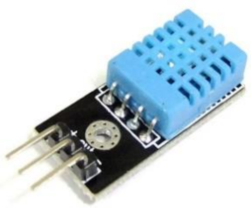


Figure 2-15 Temperature Sensor Module [23]

2.1.3. Software subsystem

2.1.3.1 Overview

Since the expression of autonomy most of the times means strong software system behind the sensors and the actuators the vehicle equipped with. For developing the top software layer that is responsible about any part of the software system we found that the Robot Operating System founded by Willow garage is the best choice. First, it’s an open source software as well it is one of the strongest robotic software development platforms if not the strongest, ROS has a wide community around the world which will allow us to emerge in the community and find support for problems we would face.

ROS has a very powerful and flexible packaging system which make it way easier to build complex software systems on top of it. The term opensource means you can use other packages and codes and directly integrate it with your own project and long as you are following the BDS license terms. Finding the appropriate packages that can be used for an AUV system to reduce time required to develop such system by using others work.

The architecture of ROS what makes very powerful for robotics projects, the need in any robotic system for real-time values from the sensors is essential so, ROS is providing the Publisher/Subscriber feature where each is a code written either in C++ or python and communication trough “Topics” which is the communication channel with a pre-defined message architecture. Also, some actions during the operation of the systems must be done, here where ROS Services/Actions come to the picture the difference between them that Services are asynchronous, and Actions are synchronous with the main program running, each package can contain Publishers, Subscribers Services and actions but it’s always better to separate packages depending on the functionality. And other features for the ease of developing a robotic system for instance (parameter server, launch files, RQT tool, RViz, URDF, etc.) with the existence of all these features and tools ROS is optimal for robotics projects development. In short, ROS is the combination of Plumbing (or communication), Tools, Capabilities and Ecosystem. These capabilities are demonstrated in the following figure:

Figure 2-16 ROS equation [24]

Vehicle controls is one of the essential elements in any autonomous vehicle software system. Our vehicle has six degree of freedom as shown in the figure (--), so writing a controller for each degree of

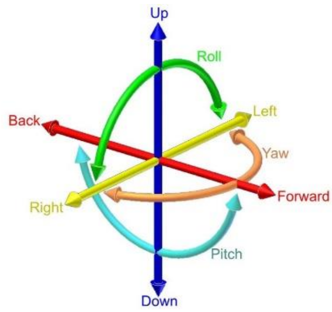


Figure 2-17 Degrees of Freedom in 3D space [25]

freedom and making sure all of them are working in harmony would be a tall order for our situation and with current knowledge we have. So, we decided to search and investigate for a convenient solution for our situation and we found the ArduPilot project which is the tool we need. ArduPilot is a project consist of various firmware for different types of vehicles such as planes, copters, rovers and subs which is the one we need in our case

ArduSub is the firmware which is built on top if ArduCopter firmware, equipped with 3 diving modes and controllers for each degree of freedom it's designed primarily to be used in ROVs system which is useful in our case for testing, but the designers had extended the capability of ArduSub to be possible for other developers to exploit it in AUVs system easily

Also, what makes ArduSub useful for us the existence of SITL simulator which allow us to start developing our own software system even before having any hardware component, as well as enable us to test the codes on a simulator before the actual hardware which is much safer.

And we can summarize the main power features in ArduSub as following [26]

a. Feedback control and stability: Based on a multicopter autopilot system, the ArduSub controller has accurate feedback control to actively maintain orientation.
b. Depth hold: Using pressure-based depth sensors, the ArduSub controller can maintain depth within a few centimeters.
c. Heading hold: By default, the ArduSub automatically maintains its heading when not

2.1.3.2 Computer Vision

Options for computer vision are very limited with OpenCV being practically the only realistic option for image processing, but within OpenCV there are plenty of options that can be used to achieve the same intended goals [27] [28], based on the intended use for the UUV there are two major goals:

a. Object detection and tracking based on known colors and shapes. object detection can be done by thresholding, Haar cascades (deep learning trained AI module), or rule-based AI, while tracking can be done using multiple methods including but not limited to centroid tracking, Deep learning algorithms (CSRT, KCF, MIL etc.) [29].

b. Detecting paths which is a very common task with many implementations available that achieve it, these implementations all follow the same basic process [29]:

1. area of interest detection (AoI)
2. edge detection
3. detection of parallel lines
4. determining most likely paths

Although the used process is the same but the way each step is achieved differ slightly from one implementation to the other.

Finally incase a stereo camera wasn't chosen a third major goal will need to be implemented in software

c. Depth detection, there are three possible software options one of which isn't computer vision dependent, but it'll still be discussed here for clarity and ease of comparison for the reader:

1. Reference dimensions: This method gives very accurate measurements for predefined target using the basic trigonometric concept of similar triangles. [30]
2. Estimated FOV thresholds: This method uses an estimated threshold for the area in the camera FOV covered by the object which will give an estimated distance range, if the object is too close it will cover an area larger than the upper FOV threshold, if it's too far it will cover an area smaller than the lower FOV threshold. [30]
3. State machine process: Using mission plan steps to move the UUV to the required distance, for example: move to touch the target -> move back at X speed for Y seconds

2.2. Concurrent Solutions

Before starting our project, we first viewed various other projects from teams that competed and excelled in previous ROBOSUB competitions such as Harbin Engineering University, Far Eastern Federal University, Kasetsart University and University of Arizona. We then analyzed their designs and noted each team's significant features which are shown in (table 2.5), such as Harbin's control system and FEFU material selection. [31] [32] [33]

Table 2-10 will describe in detail the comparison between every component we used – manufactured of purchased – and its counterpart from Harbin, Zeabus and FEFU teams. We chose to compare our work with those particular teams for two reasons. Firstly, because of their excellent performance in the RoboSub competition, and secondly because the materials and components they used are similar to what we can build with the limited resources we have.

2.3. Comparisons of the concurrent solutions

Table 2-10 Comparison of the proposed design with concurrent solutions

#	Component	Vendor	Existing			Proposed	Remarks	Effects	Cost ($)
			Harbin	FEFU	Zeabus				
1	Frame	Custom made	Polypropylene plates	Polypropylene plates ABS plastic shell	Al 6063 rods	Polypropylene Frame Al 6063 6063 Supports ABS plastic shell	Good mechanical properties Availability Ease of manufacturing	Ease of cutting and printing Better fluid dynamics; less drag	400
2	Waterproof Housing	Custom made	Custom made	Custom made; Oxidized Al 6063 and O-rings	Custom made; acrylic tube and Al 60636063	Polyamide 6 O-rings Chemical isolation	Ease of manufacturing Availability	Buoyancy close to that of water; minimum effect on cp	200
3	Waterproof Connectors	Adex Egypt	5pin 3pin	Al 6063 glands	Impulse (Teledyne), WET-CON(SEACON)	Al 6063 glands	Within budget available	Ease of application	20
4	Thruster	Blue Robotics	Custom made	N/A	T200	T200	Adequate thrust Already isolate availability	Increased speed and controllability	1000
5	Motor Configuration	-	8 Motors, 4 for lateral motion, 4 for vertical motion. Both are fixed at an unmentioned angle.	5 Motors: Lateral: 2 facing forwards at an angle and one facing sideways. Vertical: 2 motors placed to achieve pitch	8 Motors, 4 for lateral motion, 4 for vertical motion. Both are fixed at an unmentioned angle.	6 Motors: Lateral: 2 motors facing forwards, 1 motor facing sideways. Vertical: 2 motors placed at the front, 1 placed at the back.	Within budget available	Achieves 6 DoF Makes the robot more controllable and maneuverable	0
6	Torpedo launcher	Custom made	N/A	N/A	Spring loaded with electric latch (solenoid) practically: electric door lock loads spring and fires	The torpedo will be loaded by compressing a spring, the mechanism will be locked using a motor.	Available Easily manufactured	No isolation needed simple	0

7	Gripper	Custom made	N/A	N/A	N/A	Bilge motor and ball screw mechanism	Already isolated Within budget	Smooth and efficient motion	150
8	Location of torpedo	-	Lowest point	Beside the steering camera	N/A	Beside the steering camera	Eases the image processing	N/A	0
9	Location of Gripper	-	Lowest point	Lowest point	Lowest point	Lowest point	Better mass distribution	Allows manipulation objects on the sea bed	0
10	Motor Control	Blue Robotics	N/A	ESCs	ESCs	Electronic Speed Control	For ease of use	N/A	150
11	Battery	Undetermined	GESH LiPo 5000mAh	LiPo 5000mAh 22.2V	22.2V 5000mAh LiPo 60C	Li-Po 14.8V 10000mAh 25C	For longer testing time	More power distribution circuits	300
12	CPU	Intel	Nvidia jetson TX2	2 uniform computers	Intel core i5	Intel NUC i5	For ease of use	N/A	400
13	Internal Comm. Network	-	CAN USRT		Custom made	UART I2C	Widely used	N/A	0
14	Programming Language	Python C++	Python C++	Python C++	Python C++ C	Python C++	N/A	N/A	0
15	Inertial Measurement Unit (IMU)	Xsens	Fiber gyro	Xsens-mti IMU	3DM-GX5-45	MPU6000	Built in in the PixHawk	Integrated in an AHRS	180
16	Doppler Velocity Log	?	Nq600 micro DVL	RD instruments	Teledyne	N/A	N/A	N/A	N/A
17	Camera(s)	AliExpress	Stereo Cameras	Prosilica GC1380	IDS imaging development system	Isolated underwater camera CR-006A30M	Available Already isolated	Saves isolation time	250
18	Hydrophone	Teledyne	CS3V	N/A	Teledyne TC-4013	Aquarian H1c	Less resolution	Less DoA and TDoA accuracy	130
19	Manipulator	Custom made	N/A	N/A	Custom made	Custom made; ball screw mechanism			200
20	Algorithms: vision	Open CV	N/A		OpenCV	Open CV	N/A	N/A	0

21	Algorithms: localization and mapper	-	ORP SLAM	N/A	ROS	SMACH	Ease of use and better visualization	N/A	0
22	Algorithms: autonomy	-	N/A		ROS	SMACH ROS	Ease of use and better visualization	-	0
23	Open source software	Open robotics	ROS	ROS	ROS OpenCV GitHub Ki CAD Ltspice Open STM32	ROS OpenCV ArduSub	Wide community Flexibility Using functions and packages built by others	-	0
24	Team size (number of people)	-	15	8	16	5	-	-	0
25	Testing time (hours)	-	1200	N/A	90	200	-	Better calibration of the software More time for troubleshooting	0

Chapter 3 -DESIGN and ANALYSIS

3.1. Proposed/Selected design

We have made sure that our proposed design of the AUV shall be modular, easy to manufacture, easy to assemble, and cost effective. To meet these objectives, we have added a lot of features on the design such as, the possibility to change a lot of the hardware components just by changing the position of the mounting to be able to optimize the system while testing. In the electrical system to be cost effective since the components for underwater applications is quite expensive, we have chosen the necessary parts to achieve the mission objective successfully. For the software side we have built a strong algorithm and software structure to be expandable through the development of the vehicle.

In fig 3.1 you will the system break down structure with the part codes.

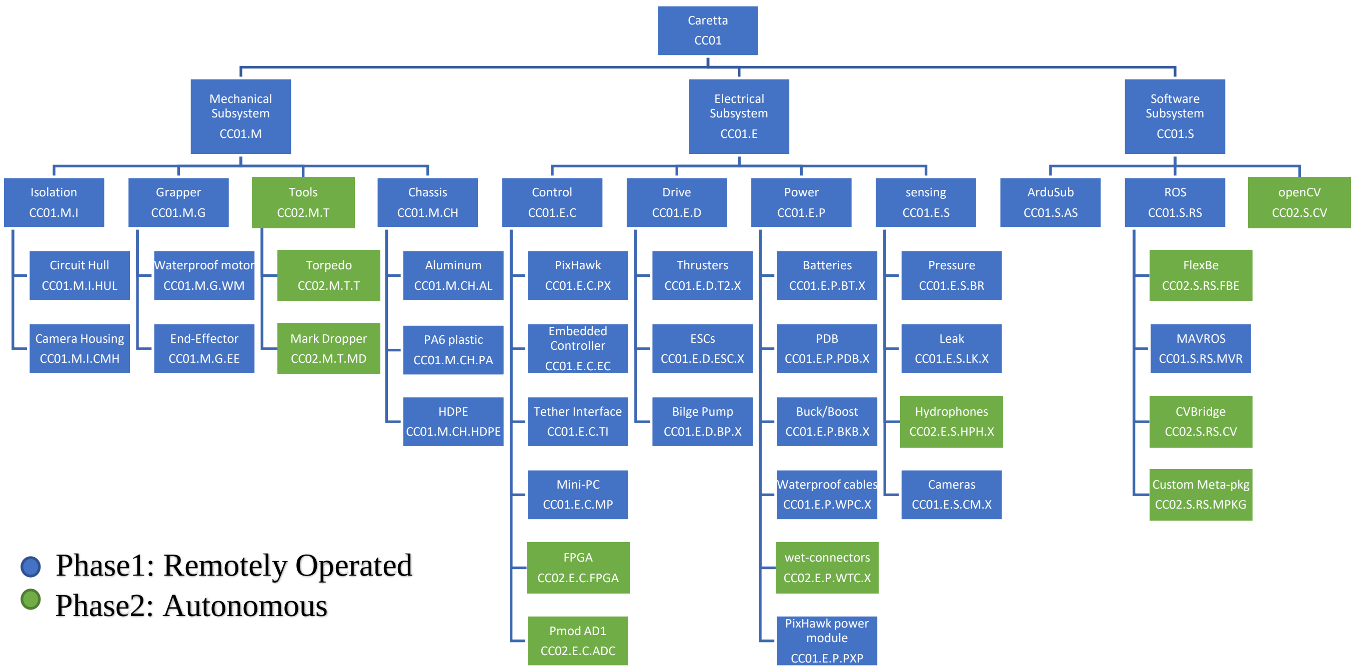


Figure 3-1 Projects Breakdown Structure

Naming conventions:

Each name consists of four parts explained as follows

X (name shortcut of the project) **.X** (Initial of the subsystem) **.X** (Initial of the sub system)**. X** (Letters to indicate the part). **X** (serial number for repeated components)

3.1.1. Phase 1

3.1.1.1 Mechanical Subsystem

3.1.1.1.1 Design Evolution

To reach the optimum design, we went through different phases and ideas. We began by studying other previous designs which participated in the ROBOSUB competition, we also spent a lot of time studying how commercial ROVs are built and manufactured. We settled for the commonly used box shaped open-frame design for its stability and ability to house most components needed. The ROV is being designed to give maximum serviceability allowing easy assembly and disassembly of parts to make any repairs as quickly as possible.

Next, we started sketching the agreed upon design using the Computer Aided Design (CAD) program SolidWorks, which was then – taking all efficiency and safety factors into consideration- finalized. All the CAD files were prepared to be machined by a Computer Numeric Control (CNC) mill ‘s Computer Aided Manufacturing (CAM) package, after converting them into Drawing Exchange Format (DXF) files. However, we were limited by the material availability and the manufacturing techniques available. Our main objective is to design a vehicle using the minimum number of components. This eases the assembly procedure while also reduces the ordering and manufacturing costs.

While designing the AUV, our aim was to:

a. Reduce the AUV’s length as much as possible.

b. Ensure that the AUV is adequately rigid.

c. Reduce the vehicle’s weight.

d. Ensure that the center of mass (CG) is directly below the center of buoyancy (CB).

e. Achieve a suitable separation between the CG and CB to obtain optimal stability. (explained in section 3.3)

f. Design for ease of assembly and maintenance.

Main Components:

a. 2 surge thrusters

b. 2 heave thrusters

c. 1 sway thruster

d. Main hull

e. Gripper

f. 2 x Side frames

g. Tube holders

h. Gripper holder

i. Support

3.1.1.1.2. Design configuration 1

In our first phase of design, we agreed on the main overall shape of the vehicle, two main side frames connected by supports, which in turn are used to mount other components. Next, we tried to make the vehicle as hydrodynamic as possible by designing a 3D shell that covers it. The design is entirely made of HDPE, fastened together using the finger-joint technique, where the supports are connected to the main side frame by interference. The gripper is mounted at the front to be facing forwards, where a camera is mounted above it, to have it in its field of view. Another camera is facing downwards to be used in recognizing the path drawn on the seabed. The overall dimensions are 834mm x 550mm x 450mm, the overall weight is 16.5 kg and the CG is below the CB by 70mm.

Figure 3-2 Design Configuration 1

3.1.1.1.3. Design configuration 2

During this phase, we used the same overall shaped agreed on, but a different more optimized side frame. We also modified the hydrodynamic shell to match the new dimensions and configurations. The chassis is also made entirely of HDPE and fitted together using the finger-joint technique. The gripper, camera and torpedo placements were also unchanged. The overall dimensions are 1233mm x 470mm x 479mm, the overall weight is 15.2 kg and the CG is below the CB by 64.9mm.

Figure 3-3 Design Configuration 2

3.1.1.1.4. Design configuration 3

This designed featured a much-improved side frame and reduced overall width. While the components placements are nearly the same, the thrusters were moved closer to the main hull, reducing the overall dimensions of the vehicle. In addition, the fitting method was changed to using 4mm bolts fastening the side frame to a hole drilled in the thickness of the supports. Next, we removed the shell as it added a lot of weight to the vehicle and replaced it by a spherical part fixed on the water-facing side of the tube, thus reducing the drag while avoiding adding weight. The overall dimensions are 912mm x 456mm x 409mm, the overall weight is 13.1 kg and the CG is below the CB by 63.4mm. Finally, we started to add some modularity to the design by giving the surge thrusters the ability to move vertically.

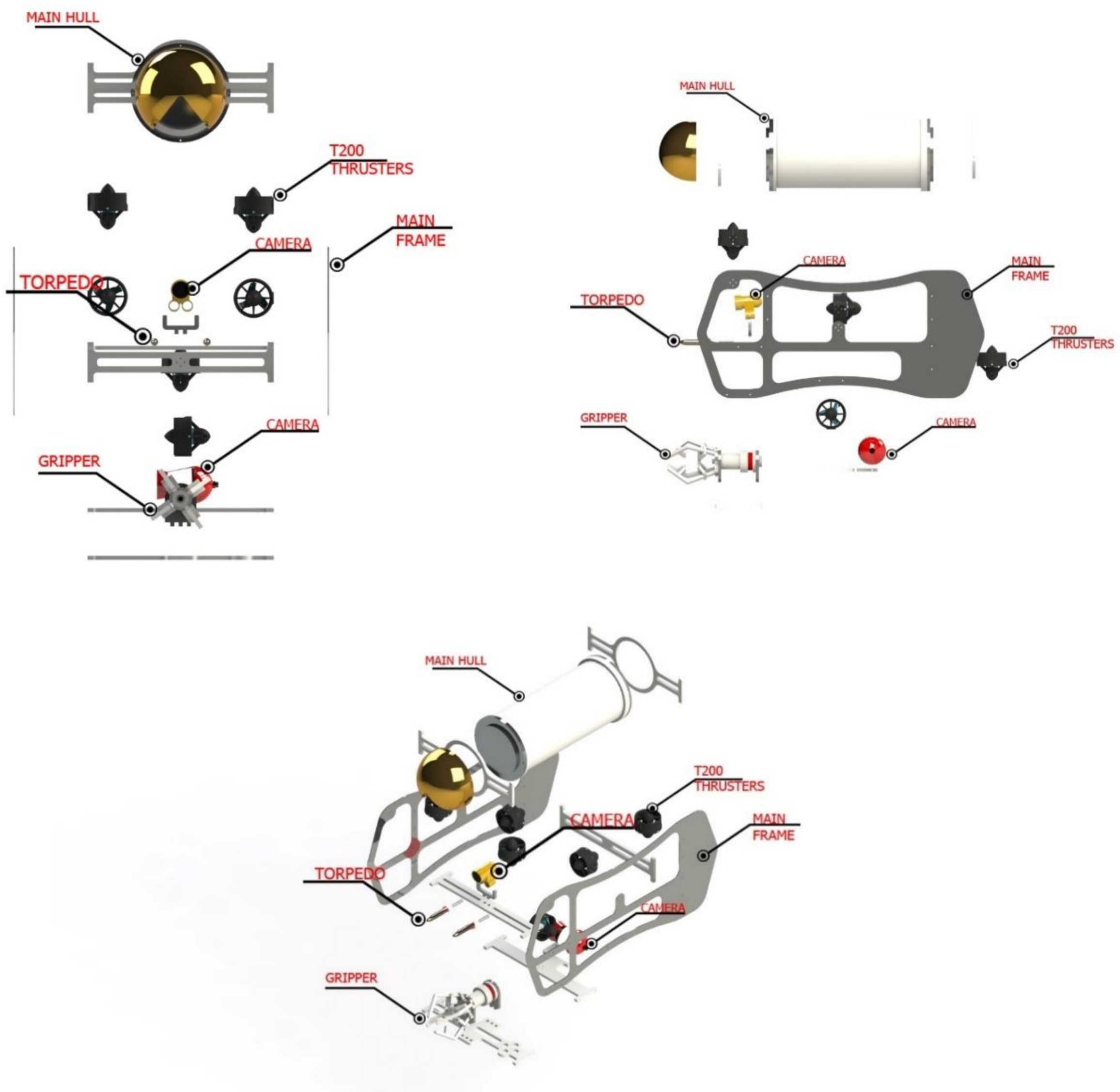


Figure 3-4 Design Configuration 3

3.1.1.1.5. Design configuration 4

The main modification in this phase was moving the gripper to face downwards as we found out that this position is optimal for doing the required mission. Accordingly, the camera placements were changed to keep the field of view as ideal as possible. Also, for availability and financial reasons, we switched back to HDPE as the main material for the side frame. The shell was slightly optimized to fit the new configuration. Next, the side frame was redesigned to provide support for the down-facing gripper. However, the new design was inefficient in terms of stability, it also had protruding parts which may be an obstacle while maneuvering in the mission probes. These problems were solved in the fifth and final design. The overall dimensions are 842mm x 470mm x 574mm, the overall weight is 13.8 kg and the CG is below the CB by 109.3mm. We also increased the design's modularity by mounting the heave thrusters on sliding parts.

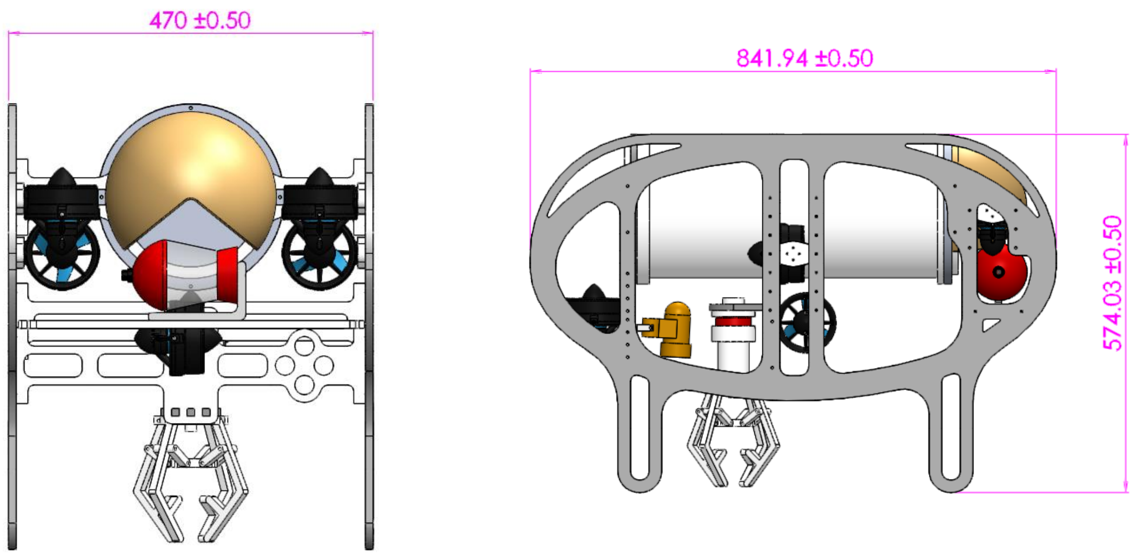


Figure 3-5 Design Configuration 4

3.1.1.1.6. Proposed Design Configuration

In the final design, we redesigned the side frame to be as topology optimized as possible, we also removed all the protruding parts. The body is made entirely of HDPE and fitted together using custom designed 3D printed parts to connect the supports to the main frame more efficiently. All the components are brought as close as possible to each other, which made the vehicle as compact as possible. The 3D printed sphere fitted on the front facing side of the main hull have been further modified to fit the new configuration. Next, we developed a new sliding mechanism for the gripper, allowing it to move linearly then rotate to fit inside the body when not in use. The fixed camera is placed facing downwards, having the gripper and the mission probes in its field of view, while the 360 rotating camera is placed at the front as a pilot camera to maximize our steering field of view. The overall dimensions are 842mm x

470mm x 427mm (574mm with the gripper in use), the overall weight is 13.3kg and the CG is below the CB by 100.3mm. Finally, we added the following modularity options:

a. Vertical and horizontal movements for the surge thrusters.
b. Vertical movement for the heave thrusters.
c. Vertical movement for the main hull

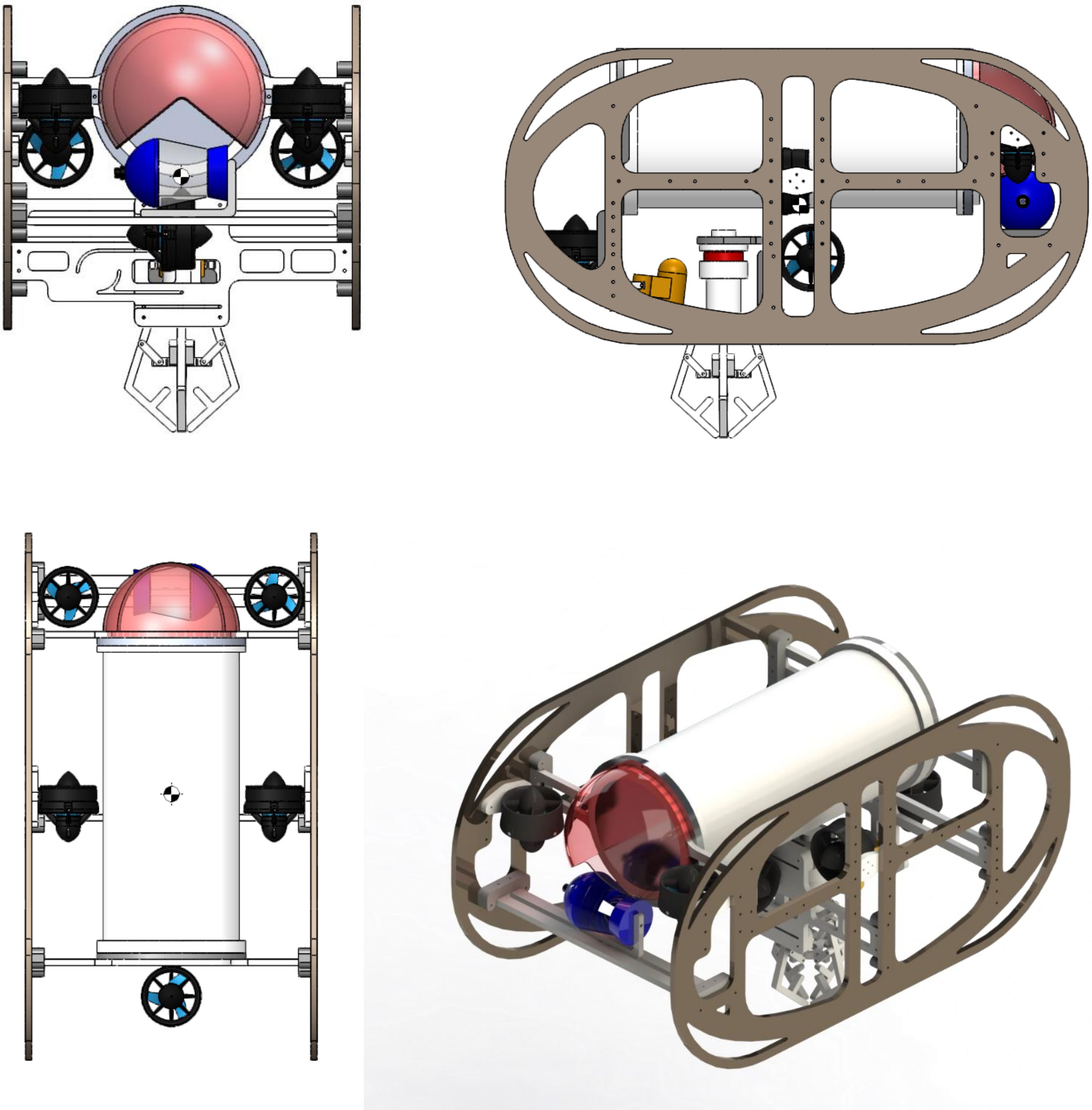


Figure 3-6 Design Configuration 5

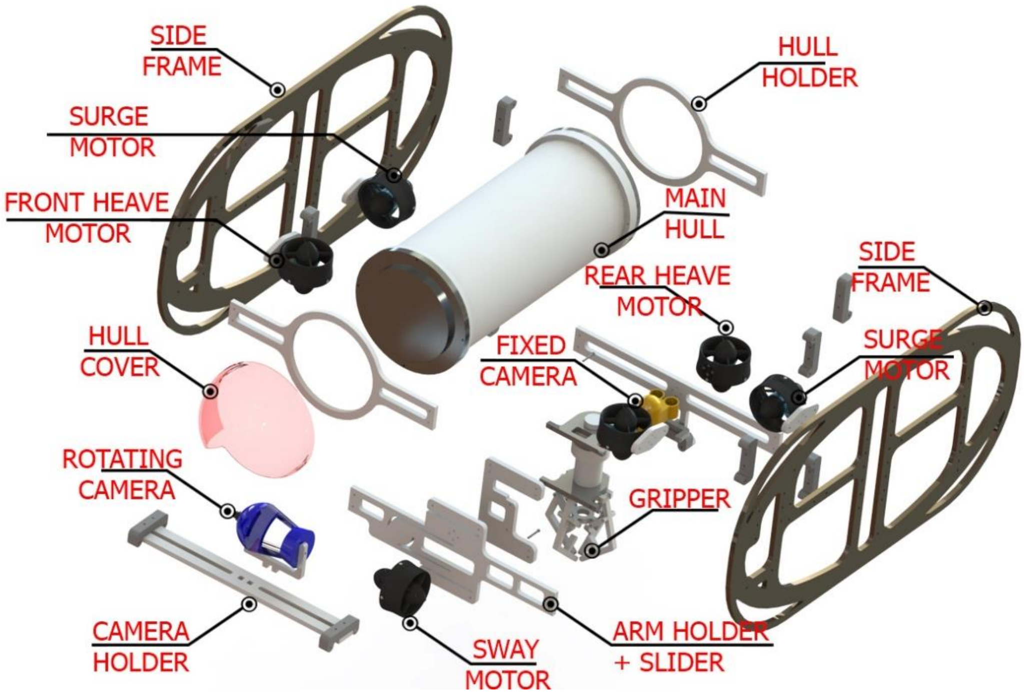


Figure 3-7 Design Configuration 5 Exploded View

Table 3-1 compares the main design evolutions through the design process:

Table 3-1 Design Configuration Comparison

	Parameter	Design config. 1	Design config. 2	Design config. 3	Design config. 4	Proposed Design config.
1	Material	HDPE	HDPE	Al 6063 + HDPE	HDPE + ABS	HDPE + ABS
2	Fastening method	Finger joint technique	Finger joint technique	4mm bolts directly on supports	4mm bolts directly on supports	Custom 3D printed parts
3	Dimensions (LxWxH) (mm)	834x550x450	1233x470x479	912x456x409	842x470x574	842x470x427
4	Weight (N)	165	152	131	138	133
5	Buoyancy force (N)	150	134	96.4	121	117
6	Gripper placement	Front facing	Front facing	Front facing	Downward-facing	Downward-facing
7	CG-CB (mm)	70 mm	64.9mm	63.4	109.1	100.3
8	Modular Design	●	●	●●	●●●	●●●●

The calculations and their method are further emphasized in section 3.3

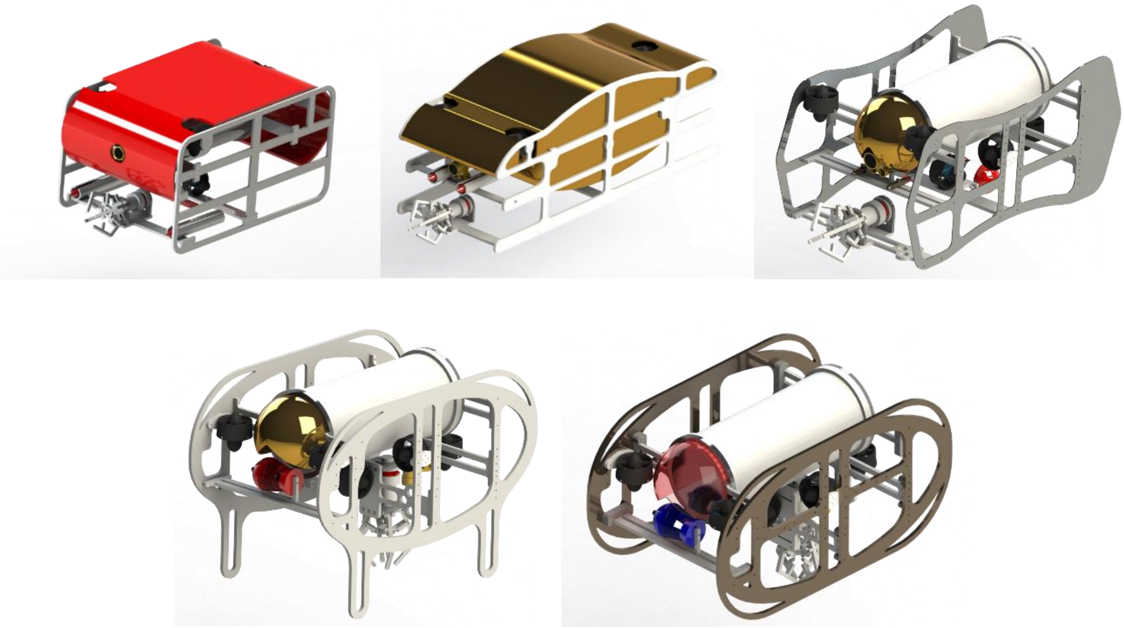


Figure 3-8 Configuration Evolution

3.1.1.1.7. Material Selection

Chosen for its lightness and rigidity, our mechanical team chose HDPE as the material of fabrication. It provided the stiffness needed while it can also be easily cut on the CNC machine. It is also widely used in the commercial ROVs and its easily attained. The density of the Polypropylene is approximately 952 kg/m3 which is close to that of water (about 1000kg/m3), this makes it easier to adjust the buoyancy of our ROV. [34] [35]

Main Features:

a) Ease of manual shaping, CNC cutting and drilling
b) Lightness
c) Rigidity
d) Good vibration properties
e) Cheap

Relevant material properties:

Table 3-2 HDPE properties

Property	Value	Unit
Elastic Modulus	$107x10^7$	N/m^2
Poisson's Ration	0.4101	N/A
Shear Modulus	$377.2x10^5$	N/m^2
Mass Density	952	Kg/m^3
Tensile Strength	$221x10^5$	N/m^2

3.1.1.1.8. Motor selection: [36]

The T200 Thruster is a patent-pending underwater thruster designed specifically for marine robotics. The T200 is basically a brushless electric motor. This motor is purpose-built for use in the ocean and was designed specifically for use on ROVs, AUVs, and robotic surface vehicles. Thanks to its compact

Figure 3-9 T200 Thruster [24]

design, it fits perfectly in our ROV. The T200 is made of high-strength, UUV resistant polycarbonate injection molded plastic. The core of the motor is sealed and protected with an epoxy coating and it uses high-performance plastic bearings in place of steel bearings that rust in saltwater. Everything that is not plastic is either Al 6063 or high-quality stainless steel that doesn't corrode. A specially designed propeller and nozzle provides efficient, powerful thrust while active water-cooling keeps the motor cool. Unlike other thrusters, our design doesn't have any air- or oil-filled cavities – water flows freely through all parts of the motor while it's running and can handle extreme pressures. The thruster is easy to use: just connect the three motor wires to any brushless electronic speed controller (ESC) and you can control it with an RC radio or a microcontroller. It's usable with Arduino, Raspberry Pi and many other embedded platforms. It's operating voltage 6-20V and maximum current is 25 A

3.1.1.1.9. Motor Configuration

To achieve all need Degrees of Freedom (DoF) with the six motors available, we placed 2 motors facing forwards to allow the vehicle to surge and yaw, we also placed 1 motor facing sideways to add swaying capability. Next, we fixed 2 motors vertically at the front and 1 motor at the back of the vehicle as shown in the figure, this allows the vehicle to roll, pitch and heave efficiently. [37]

The motor placements are crucial for not only they dramatically affect the center of mass of the vehicle, but also any misplacement could alter its stability. We also had to place them in a configuration that boosts our performance in the competition. Taking all these aspects into consideration, we placed the surging motors between the center of buoyancy and the center of gravity to maintain stability by reducing the moment effect, then we placed the vertical motors at the top of the vehicle to prevent the vehicle from surfacing, which disqualifies us from the competition. [26]

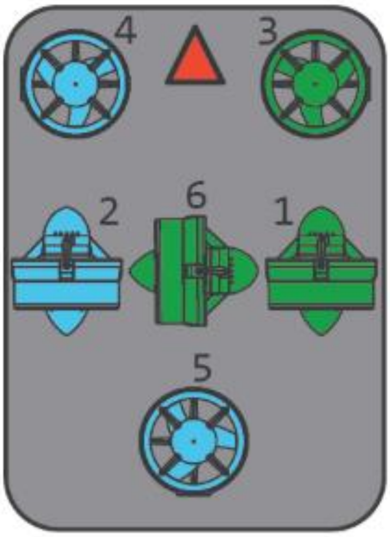


Figure 3-11 Proposed Motor Configuration [14]

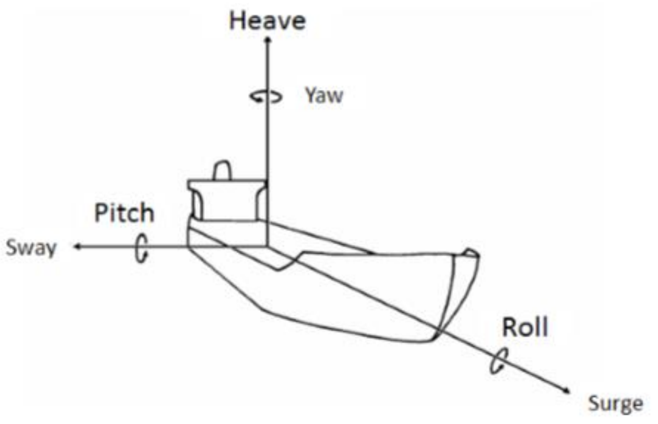


Figure 3-10 DoFs Explanatory Diagram

3.1.1.1.10. Isolation

Our main hull's design is crucial as it houses the electrical and controlling components. The hull is divided into three main parts:

Table 3-3 Hull main parts

Part	Feature
Al 6063 Cap	Fitted with 2 O-rings, made of Al for its good heat transfer capability
PA6 Cap	Fitted with 2 O-ring, made of PA6 to ease drilling in it to pass the cables into the tube.
PA6 Tube	Electrical components housing. 600mm long 200mm in diameter

Other than O-rings, we used isolating chemicals to ensure that no water passes through. These chemicals are described below:

Table 3-4 Chemical Isolation Compounds

Chemical	Use
Marine Silicon	Applied to the edges between the caps and the tube and to the penetrators
Silicon grease	Applied between the outer diameter of the caps and the inner diameter of the tube

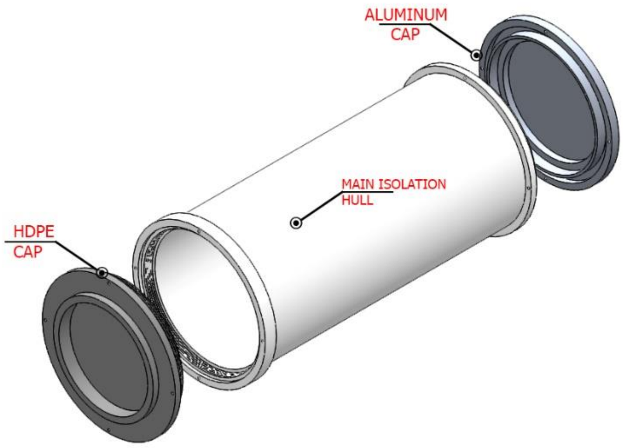


Figure 3-12 Isolation Hull

3.1.1.2.11. Manipulator

We chose a bilge motor to power the arm as it is already isolated. This motor is placed inside a PA6 housing to ease its mounting on the ROV (as shown in the figure). Next, this motor opens and closes the end-effector using a ball screw. [38]

We chose the ball screw for its useful functions, such as its low friction and zero backlash. In addition, it transfers the rotational motion to linear smoothly, which is perfect for a reliable operation. The end effector is designed as shown to be able to grab objects with various shapes and dimensions.

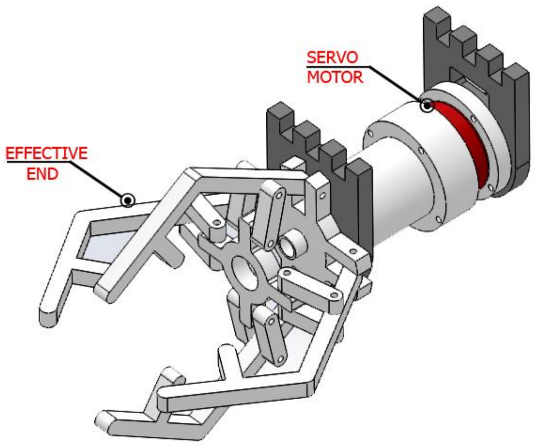


Figure 3-13 Manipulator Configuration

3.1.1.2. Electrical Subsystem

In an Electrical manner we can have the design to be a schematic of the circuitry and type of connection of the system as well as type of communication protocol to be used to communicate between other devices. The schematic which is shown in Figure 3.10 describes the whole system connection and requirements so that it can be followed to build such systems and test it using a simulator or practically.

3.1.1.2.1 Power System

Battery: The battery used has a voltage rating of 14.8VDC and a capacity of 10Ah, and three of these batteries will be used to have less load at the output of the batteries terminals and also it was chosen to reduce the need of the voltage regulation since the thrusters will be connected to the battery through the ESCs, and the diving time will be more than those batteries of less capacity.**Invalid source specified.**

Cameras: The cameras used are already isolated and available and they take 12VDC to operate [40] [41], that's why we should use a Power Distribution Board (PDB) to distribute the power between The Intel NUC and the cameras that will be somehow connected to Intel NUC.

Voltage Regulation: Since we are using a 14.8VDC Li-Po battery we need a voltage regulator as it would provide less voltage to operate The Arduino Mega, gripper and the torpedo launcher safely, and that regulator is a buck converter and we have chosen it because it's better than the normal voltage regulators because we don't need more heat inside the enclosure.

Although these converters create a magnetic field around them, we chose them because they wouldn't affect the system inside the enclosure and the acoustic system will be outside the enclosure hence, no distortion will be generated at the acoustic output.

Main Control Unit: The PixHawk 1 includes a power module connection that takes its power from the battery (which means that the power module has a built-in regulator) and gives an output of the same voltage that the battery gives (this case is similar to PDB principle).

Kill Switch: The PixHawk provide a feature where you can connect your kill switch to it and shut off the motors when pressing the button since these motors are connected to the PixHawk via the Electronic Speed Control (ESC).

Power Distribution Board (PDB): The Matek PDB board was chosen because it has a built in BEC that produce a regulated voltage of either 5VDC or 12VDC which can be used to power the cameras without voltage regulation. Plus, it has 6 outputs where you can power the T200 motors using only one battery which is not the case that we are going to follow but it may be used whenever a battery gets damaged.

Electronic Speed Control (ESC): The ESC to be used is the basic BlueRobotics ESC that is made especially for this thruster and it can be programmed using the PixHawk 1.

Gripper System: The Bilge motor will be connected to the Gripper and controlled by an Arduino Mega which will be powering the servo as well.

3.1.1.2.2 AHRS and embedded controller

We are using as an Attitude heading and reference system (AHRS) the PixHawk board for various reasons as following

a. PixHawk MPU6000 as main accel and gyro, ST Micro 16-bit gyroscope and ST Micro 14-bit accelerometer/compass (magnetometer) all integrated as an AHRS
b. PixHawk can be connected to a pressure sensor directly
c. Have a pre-built kill switch for safety concerns
d. Supports the ArduSub firmware intended to be used as we are going to discuss in the software subsystem
e. Can be connected directly to the electronic speed controller (ESC) to precisely control the motors
f. I2C, SPI, 2x CAN, USB interfaces which can be integrated with various sensors
g. Built especially for vehicles
h. Open source

So PixHawk can save a lot of time and effort that can be exploits in other complex systems to be designed. We will use the PixHawk 1 since it's the which is fully tested and supported by the developers of ArduSub the control firmware.

Figure 3-14 PixHawk 1 [29]

3.1.1.2.3 Communication Protocols:

a. Intel NUC and Embedded boards such as Arduino and PixHawk will be Universal Asynchronous Receiver and Transmitter (UART) protocol will be used.

b. Arduino and SOS leak sensor I2C protocol will be used because of compatibility.
c. PixHawk and sensors such as Bar30 I2C protocol will be used.
d. The acoustic board and Intel NUC haven't been determined yet because the team hasn't decided about what board to use.

3.1.1.2.4 Cameras

A USB mono camera was selected for its low cost and ease of use and integration with software components, the camera is also pre-isolated this choice was made despite the increased cost for the increased safety and reliability of commercial isolation.

3.1.1.3. Software Subsystem

The on-board Mini-PC that directly controls the UUV, will be connected to a surface computer in the control station, using an Ethernet cable tethered to the vehicle on one end and connected to the surface computer on the other.

The connection between the two computers will be established as a TCP port opened over SSH, once a connection is established each computer will be running its own node of Robot Operating System (ROS) and all exchange of information and instructions will be done using ROS topics and messages, enabling us to develop a modular system that can be easily expanded.

The surface computer will have a graphical user interface, built using Qt library which is a Python library used to develop graphical interfaces, this interface will allow the user to change some vehicle parameters and options on the fly such as thruster speed, the interface will show a live video stream from the cameras installed on the vehicle, it will also provide information about the state of the vehicle including current depth, heading and temperature inside the isolation hull, finally the interface will give a warning to the operator in case of an emergency

such as leak detection.

Finally, the vehicle will be controlled by the pilot using a PlayStation4 Controller, the controller was chosen for its ease of use and intuitiveness making the task of navigating the UUV easier for the pilot.

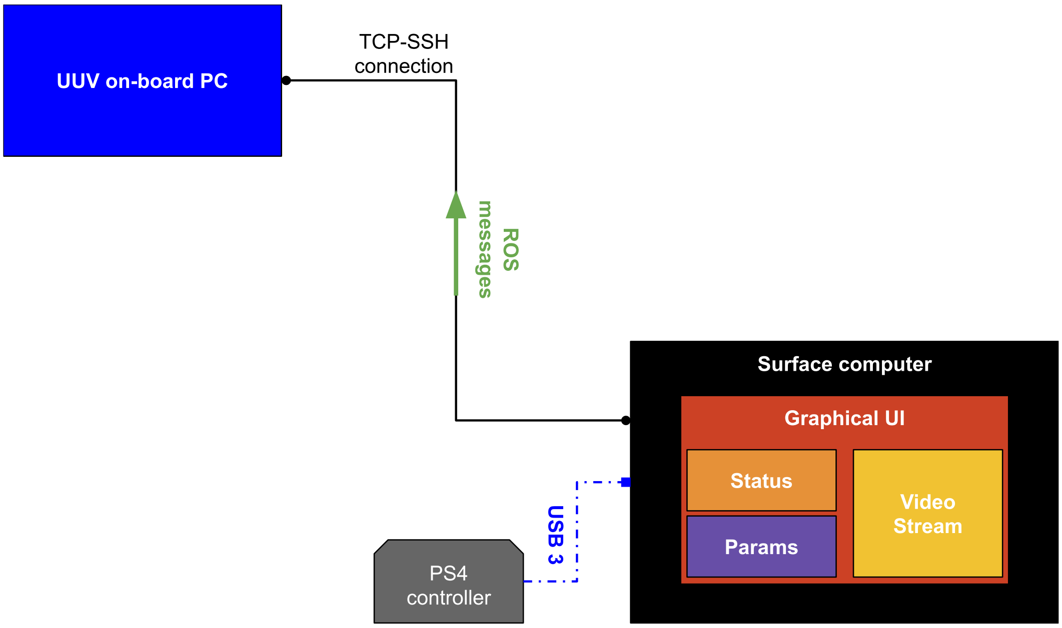


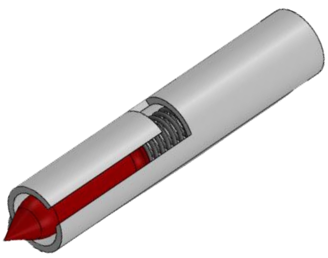
Figure 3-15 External Interface Diagram

3.1.2. Phase 2

3.1.2.1. Mechanical Subsystem

3.1.2.1.1 Torpedo Mechanism

Since decided as a team we are going to use loaded spring mechanism to achieve the attempted target, it will be very simple, and we don't need isolation, and this will give an advantage in weight, isolation and time saving. A cylinder with 200 mm as maximum length and 100 mm max diameter will be hollow from inside the spring will be fixed at the bottom and torpedo will be put inside the cylinder and then the latch, a bilge motor will be used to unlock the latch, this motor is readily isolated and have small weight and adding a shaft attachment to transform radial motion to linear motion, this is very effective way and was used by many students who competed before. We have plan B and C in case we tested this method and it fails but the other methods will add more weight and more isolation and most importantly they will add a lot of time.



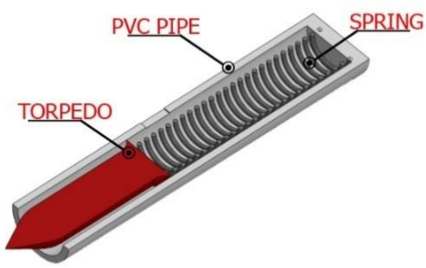


Figure 3-16 Torpedo mechanism

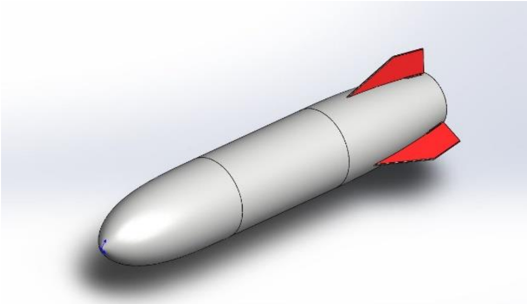


Figure 3-17 Torpedo Configuration [39]

Applying computational fluid dynamics to the torpedo and adding the parameters of velocity and pressure, also adding material properties for the torpedo which is ABS, all these parameters help the CFD software to be as accurate as possible and generate a good meshing for the torpedo. In our design the torpedo showed a perfect turbulence effect on the torpedo with the achieved speed as shown in Fig 3.11

Also, Fig 3.12 showed the materials used in the torpedo which was RED for the ABS plastic parts and the rest is the enclosure part which is sea water in our case

The Fig 3.13 shows the meshing of the torpedo and the enclosure in which a medium refinement was made to produce 89438 nodes and 388486 which is a little bit big number related to the torpedo, but it gives more accurate simulation

The next Fig 3.14 shows the result of the simulation at 0.5 m/s speed for the torpedo and showed the inlet (velocity) and showed the outlet (pressure) also fins of the torpedo affected the mass flow graph but the fins are necessary for the stability of the torpedo, this effect was shown in the figure which means the simulation was quite good.

3.1.2.1.2 Torpedo CFD

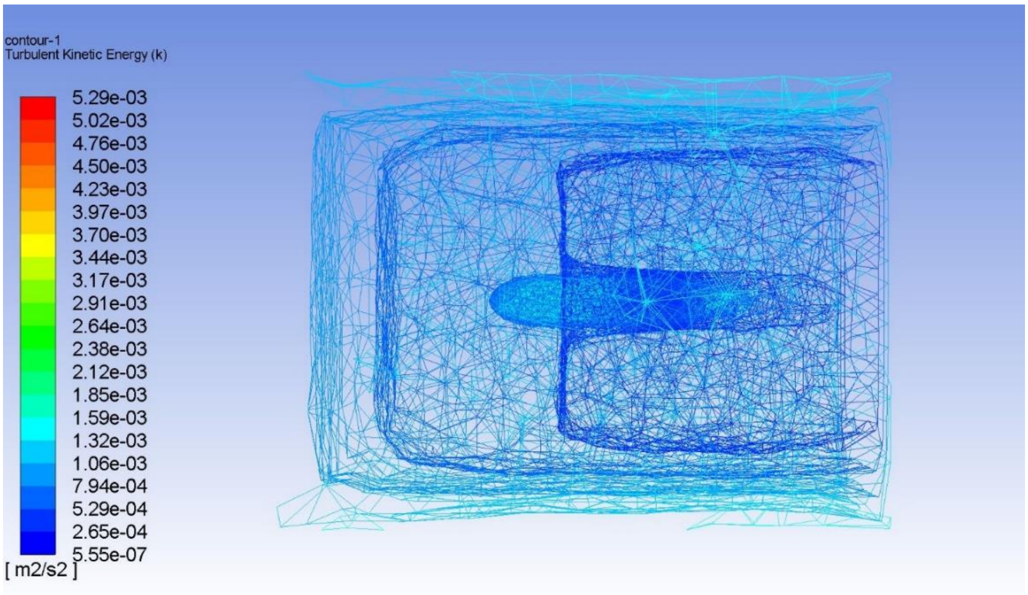


Figure 3-18 Torpedo flow analysis (a)

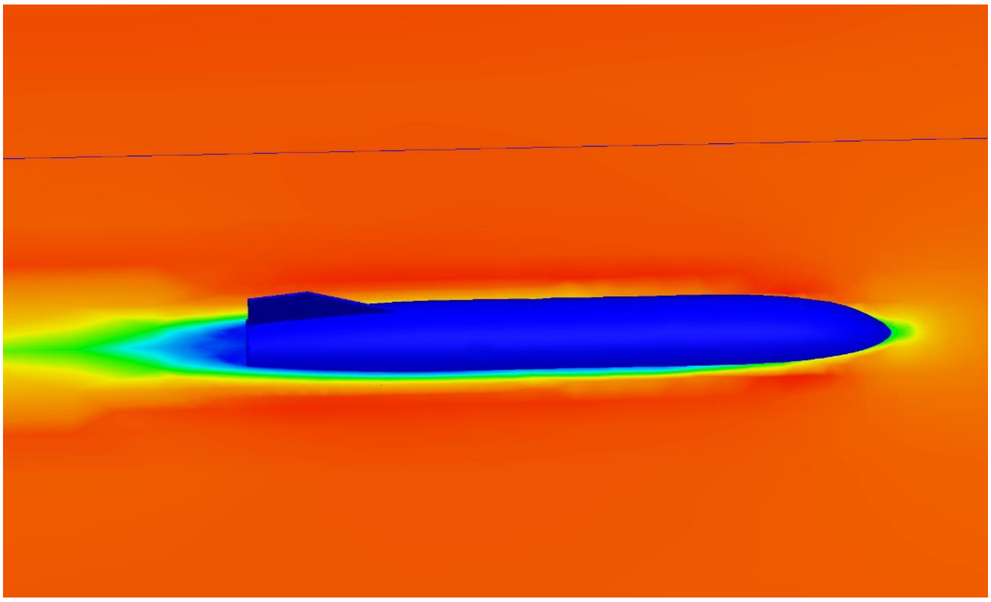


Figure 3-19 Torpedo flow analysis (b)

3.1.2.2. Electrical Subsystem

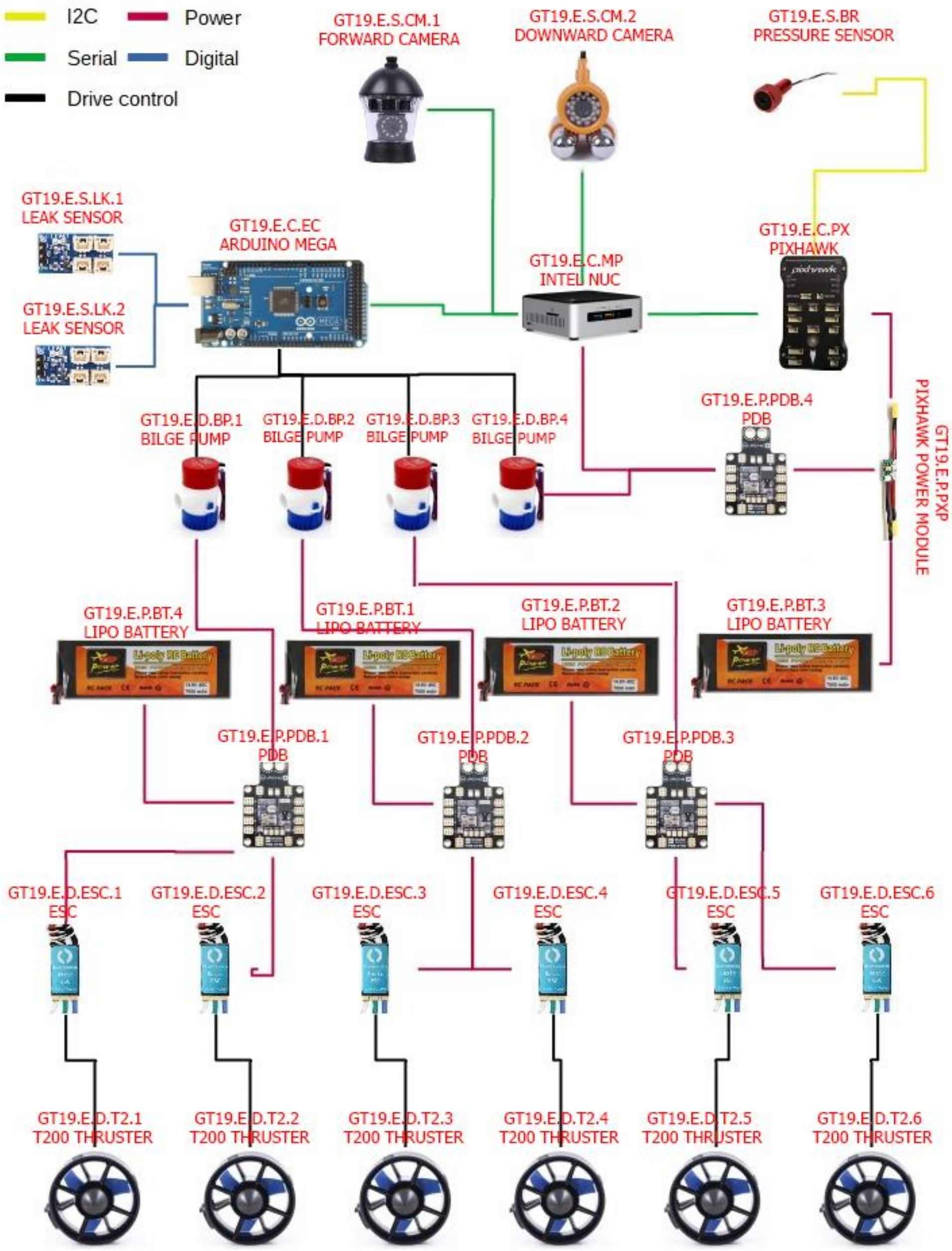


Figure 3-20 The main electrical schematic

3.1.2.2.1 Sonar system

One of the most challenging systems for us to develop is the sonar system which should be used twice to guide the vehicle during the ROBOSUB mission. The main idea of this system is to localize the position of the sound source and make the vehicle move to that position. Fortunately, there are various algorithms (namely DoA (Direction of Arrival) algorithms) and they mostly result a 2-D position. For example, finding DoA is done usually by the use of MUSIC (Multiple Signal Classification) algorithm or by the use of the cross-correlation algorithm.

In order to accomplish such tasks, there are two different solutions which are ready for Plug-and-Play components (i.e. DAQ devices) and they are too expensive, and a combination of different Sensors and development boards to have this task done (Cheaper yet harder way).

3.1.2.2.1. Digital Filter Design

a) Check the frequency range of the transducer (the source of the sound signal)

Figure 3-21 ALP 365 Benthos Pinger (Transducer) *[42]*

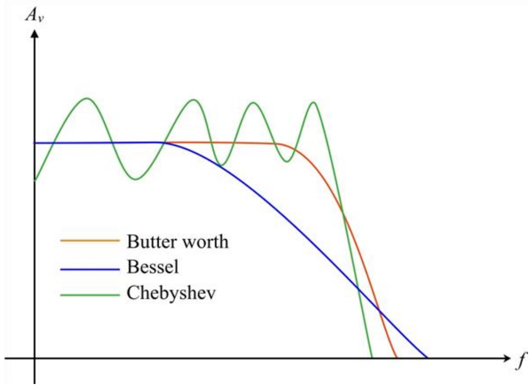
Figure 3-20 shows the ALP 365 Pinger which is exactly the same one used in RoboSub competition.

b) Define the type of filter to be used (i.e. Active or Passive)

The only difference between active and passive filter is that the active filter modifies and attenuate the amplitude of the incoming signal where the passive does not.

c) Define the subdivision of filter to be used (i.e. Chebyshev, Butterworth or Bessel)

Each of the subdivision listed is used depending on the application requirements. For instance, Chebyshev filter has the fastest step response (fast roll-off).



d) Define the frequency region to be passed and the region to be blocked

These regions are called "Pass band" and "Stop band", and there is another region which is important in designing the filter which is "The transition band" that defines the region in between.

3.1.2.2.2. Sensor Array Installation

In order to define the way that the array to be arranged, one should consider the following parameter.

$$side\ length = \frac{v}{2f} = \frac{1484\ \frac{m}{s}}{2 * f} \tag{3.1}$$

Equation (3.1) shows the maximum side length between array elements in order to avoid aliasing. (Note: 1484 is the speed of light underwater)

3.1.2.2.3. Computation

After taking the first two steps of the design here comes the final step to take the values gained from the array. Since these values are sensitive to time one need to get the values and process them as fast and accurate as possible, in order to do that as mentioned in chapter 2 Arty A7 board was chosen to complete the system.

Firstly, the process to be taken is:

a) get the values from the array and convert them into digital form by the use of external ADCs of high resolution (12-bits) to have better results

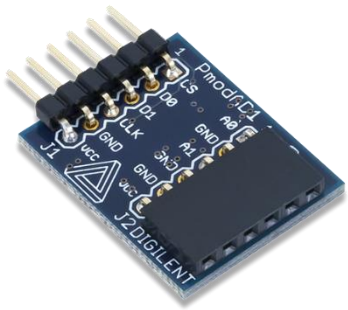


Figure 3-22 Pmod AD1 ADC *[43]*

Figure 3-21 shows the proposed external ADC to be used.

b) use the values to find the phase of each signal at the input port

c) process the information to tell where the signal came from

d) Finally, the processed value is to be transmitted to the Mini-PC via UART communication protocol in order to take actions (sending signals to motors to the determined direction).

3.1.2.3. Software Subsystem

The software system consists of different layers to control the AUV in a very efficient way to accomplish the mission. We will build our own custom meta-package on top of ROS which will consist of other packages each package will be responsible of a certain subsystem in the vehicle. Each package will consist of the required and the necessary ROS services, actions and nodes.

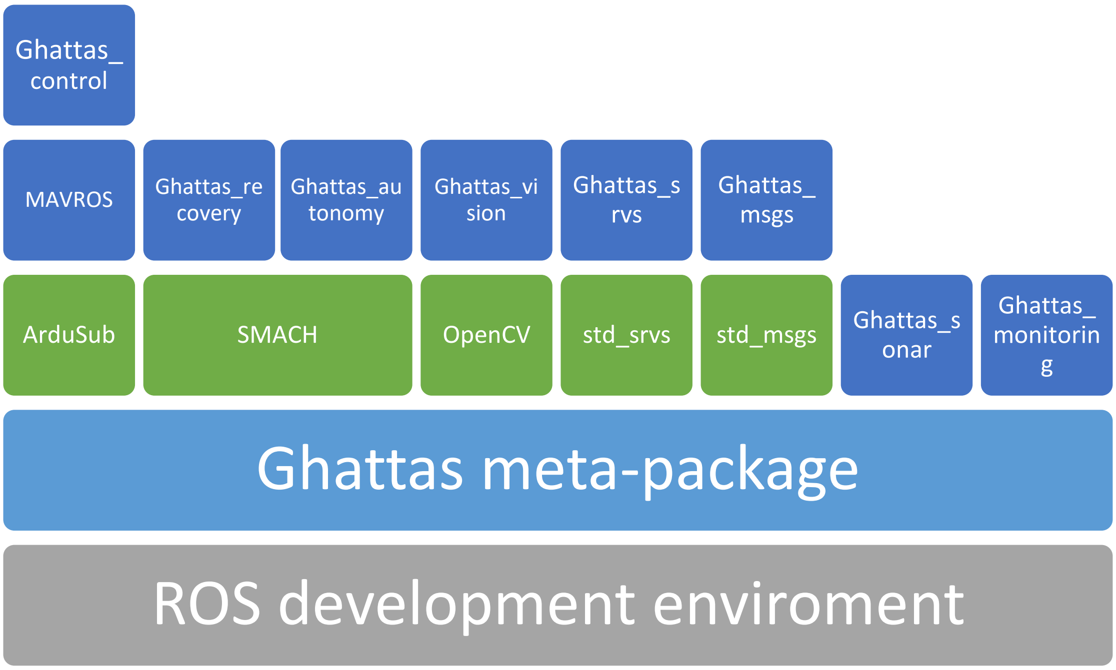


Figure 3-23 Layers Break down of the software system

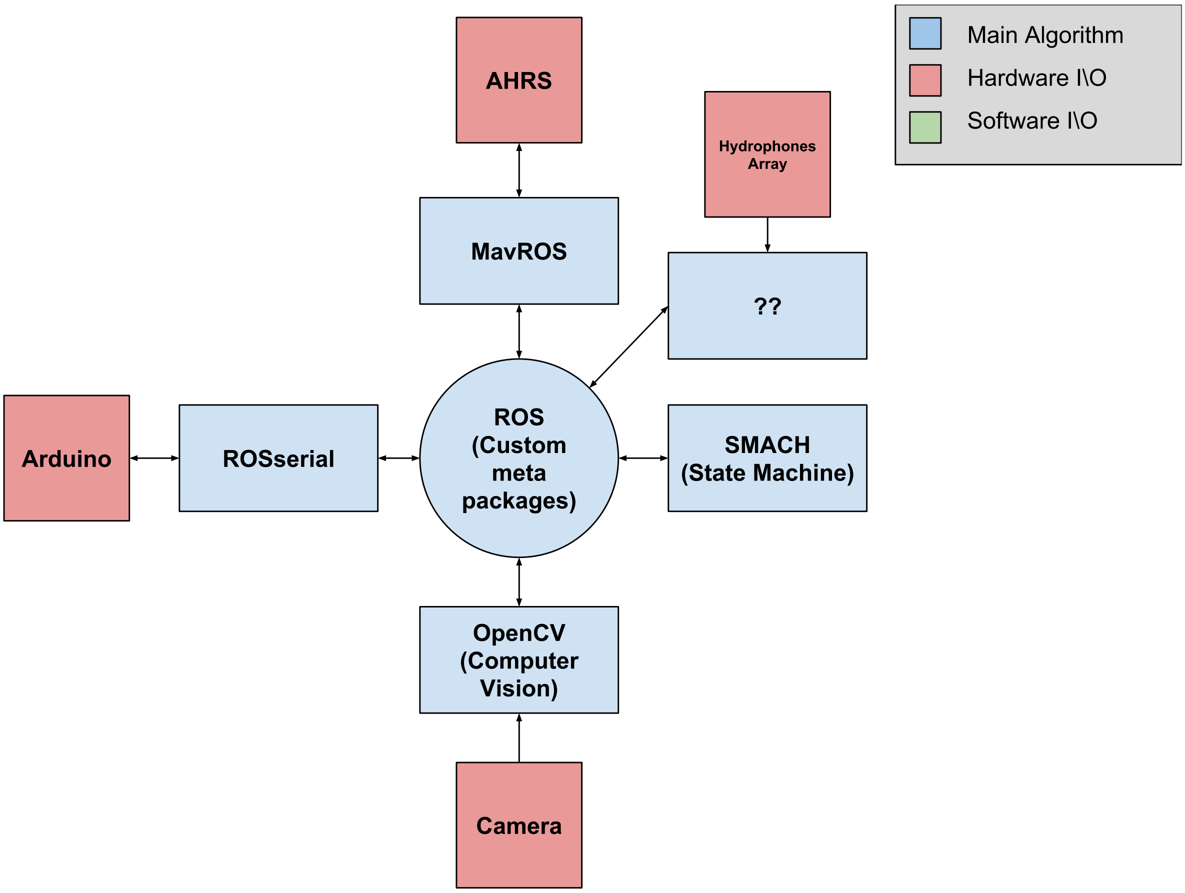


Figure 3-24 Overview of the software subsystem

3.1.2.3.1. Robot Operating System (ROS)

Why ROS is chosen can be summarized in the following points

a. Collaborative development: As we discussed, ROS is open source and free to use for industries and research. Developers can expand the functionalities of ROS by adding packages. Almost all the packages of ROS work on a hardware abstraction layer, so it can be reused easily for other robots. So, if one university is good in mobile navigation and other in robotic manipulators, they can contribute that to the ROS community and other developers can reuse their packages and build new applications.

b. Language support: The ROS communication framework can be easily implemented in any modern language. It already supports popular languages such as C++, Python, and Lisp, and it has experimental libraries for Java and Lua.

c. Library integration: ROS has an interface to many third-party robotics libraries, such as Open Source Computer Vision (Open-CV), Point Cloud Library (PCL), Open-NI, Open-Rave, and Orocos. Developers can work with any of these libraries without much hassle.

d. Simulator integration: ROS also has ties to open source simulators such as Gazebo and has a good interface with proprietary simulators such as Webots and V-REP.

e. Code testing: ROS offers an inbuilt testing framework called **rostest** to check code quality and bugs.
f. Scalability: The ROS framework is designed to be scalable. We can perform heavy computation tasks with robots using ROS, which can either be placed on the cloud or on heterogeneous clusters.
g. Customizability: As we have discussed, ROS is completely open source and free, so one can customize this framework as per the robot's requirement. If we only want to work with the ROS messaging platform, we can remove all the other components and use only that. One can even customize ROS for a specific robot for better performance.
h. Community: ROS is a community-driven project, and it is mainly led by OSRF. The large community support is a great plus for ROS, and one can easily start robotics application development.

Our software design is mainly a meta package consist of packages categorized depending on functionality so each package is responsible for only one function in the ROV our software design can be as described in the following table:

Table 3-5 List of designed packages and their functionality

Package Name	Package functionality
Caretta_msgs	Organize the main communication architecture between Publishers/Subscriber in the whole system
Caretta_srvs	Define the appropriate service message for the whole system with appropriate data types
Caretta_sonar_localization	Acquiring the signals coming from the acoustic circuit Estimate DoA and give an angle as a result Estimate TDoA with a distance as a feedback
Caretta_vision	Path following to guide the vehicle Navigate through a color-coded gate
Caretta_autonomy	Taking decision for using the state machine to perform a pre-defined mission
Caretta_control	Responsible to stabilize the vehicle Provide services to move the vehicle in any direction (Heading_to, Save_heading, Heading_to_saved, Move_forward, Move_backward, Move_right, Move_left, Pitch, Dive_to, Save_depth, Dive_to_saved, Fire_torpedo, Gripper_hold and Gripper_release) Launching the torpedo Precision grapping system to control the manipulator
Caretta_recovery	Provide recovery behaviors in case of lost
Caretta_monitoring	Monitor the vehicle and take actions before serious damage could happens

More explanation about how our main two packages working is described below which they are the autonomy package and the control package

a) Caretta_autonomy

This package is the decision maker. For autonomy we will exploit the power of state machines since the mission is well described and somehow, we can predict the actions needed. SMACH is a ROS package which allow us to build a state machine as visualizing it in the figure is an initial state machine for our proposed design and all the functionalities there is tested on the SITL simulator

b) Caretta_control

The ArduSub firmware which we are considering it as our main control program has three diving modes

a. Manual mode: passes the pilot inputs directly to the motors, with no stabilization. ArduSub always boots in Manual mode.
b. Stabilize mode: is like Manual mode, with heading and attitude stabilization.
c. Depth Hold: is like Stabilize mode with the addition of depth stabilization when the pilot throttle input is zero. A depth sensor is required to use depth hold mode.

Of course, performing such hard mission needs good control system behind and, in this package, we are exploiting the MAVROS package to communicate with the PixHawk since the PixHawk is using the MavLink protocol for communication and receiving commands and give feedback to the system, so a ROS driver is a must and that what we found in MAVROS. Also, the control package is responsible for the torpedo and gripper systems by communicating with the Arduino Mega using the ROSSerial package.

The control package will have various ROS services to control the AUV in any direction required the initial services written and tested on the SITL simulator is as following.

3.1.2.3.2. OpenCV

Computer Vision algorithm:

This algorithm was designed to be simple, modular where every step can be modified without the need to modify the steps before and after it [27] [28] :

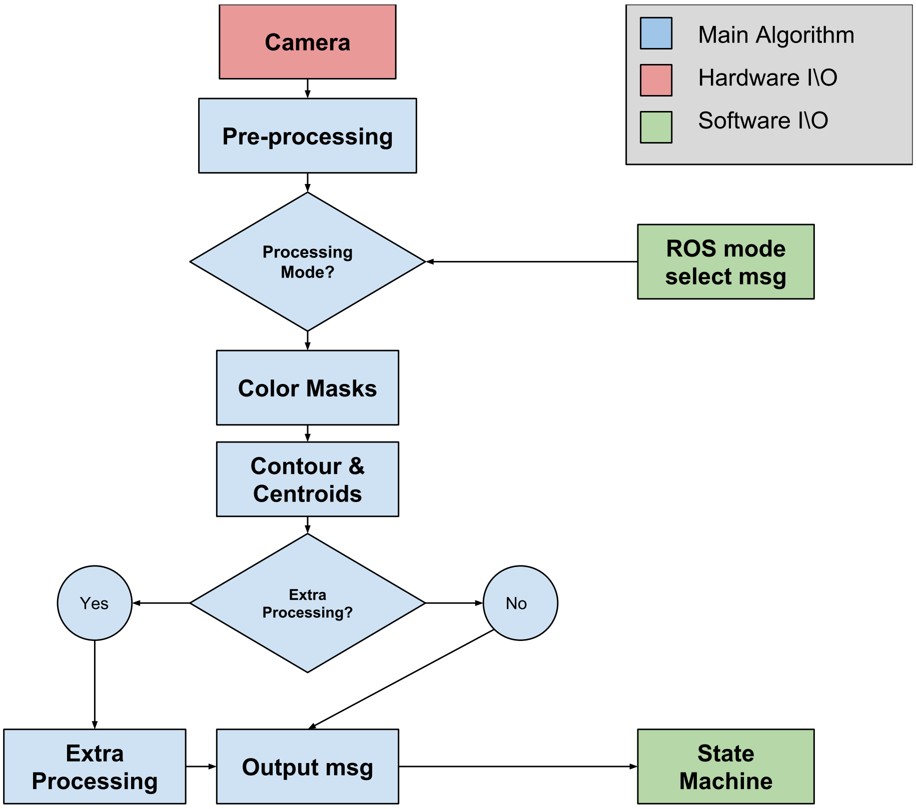


Figure 3-25 Computer Vision Algorithm

Extra Processing:

1- Path Detection algorithm:

The path detection algorithm uses a very standard process, that starts by detecting the marker using color isolation followed by edge detection (contour), and finally recognizing the most likely path using parallel line detection [27] [28]:

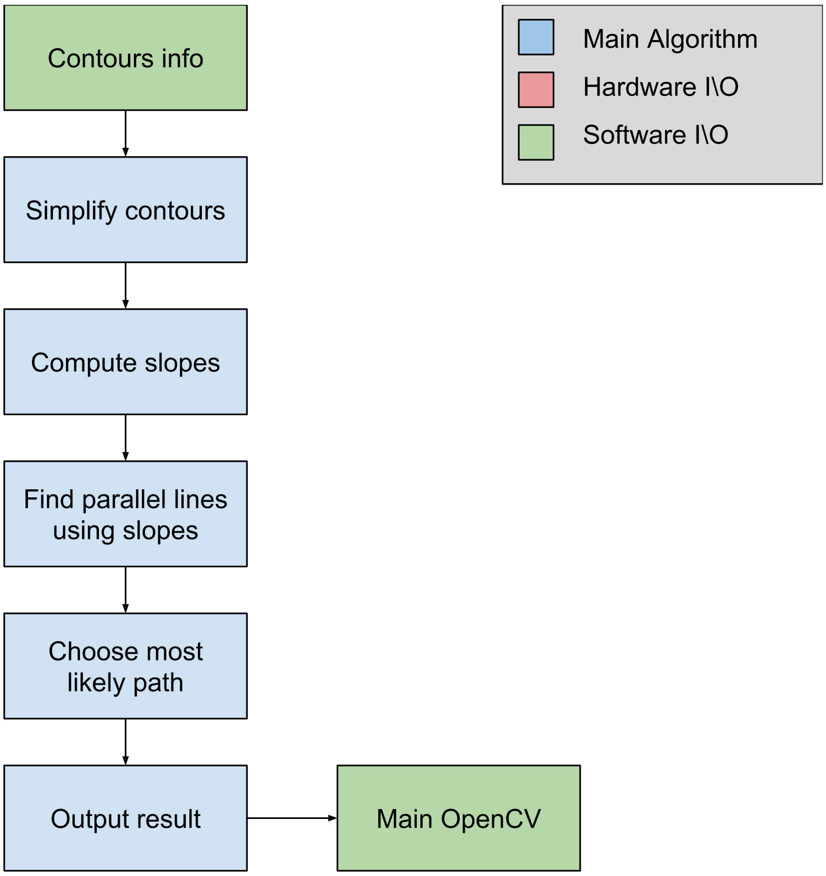


Figure 3-26 Path Tracing Algorithm

2- Object distance computing algorithm:

Object distance in our UUV will be detected using a software implementation, since we can't afford the cost of a hardware solution such as stereo cameras, this software solution will require prior knowledge of the object dimensions to detect its distance from the camera, it will also require knowledge of the camera focal length and sensor size, which both can be obtained through the camera data sheet or through testing and calibration, once all these information are obtained the object distance and orientation can be obtained using basic transformation and projection calculations [30] :

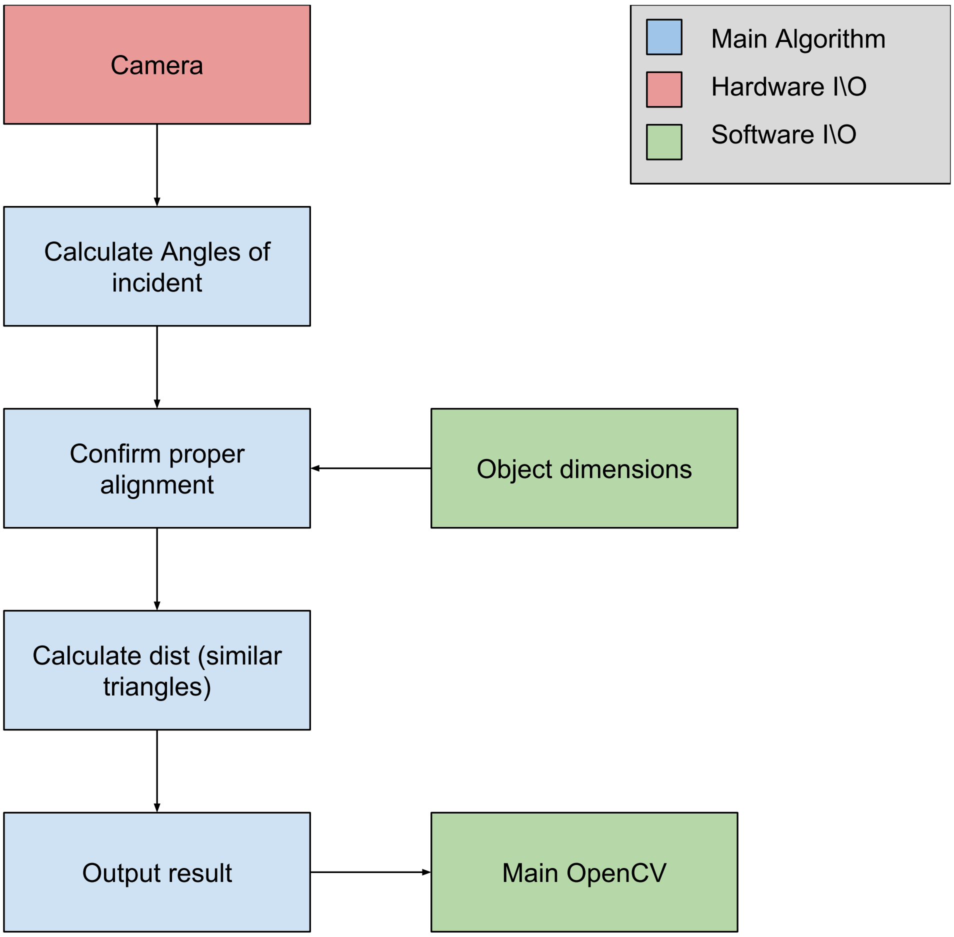


Figure 3-27 Depth Estimation Algorithm

3.2. Engineering standards

3.2.1 Mechanical Subsystem

There are some standards and regulations that our AUV must meet. Firstly, For the ROBOSUB competition, each entry must fit within a six-foot long, by three-foot wide, by three-foot high "box" (1.83m x 0.91m x 0.91m). Also, the vehicle's weight must be less than 56.7 Kg to be allowed to compete. However, a vehicle less than 22 Kg will be given bonus points as shown in the figure below:

Table 3-6 RoboSub Weight Constraints [2]

Weight (kg)	Bonus	Penalty
AUV >56.7	N. A	Disqualified
56.7≥ AUV >38	N.A	Loss of 250+11*(kg-56.7)
38≥AUV>22	Bonus of 4.4*(38-kg)	N.A
AUV≤22	Bonus of 80+2.2*(22-kg)	N.A

We also followed the Code of Practice for The Safe and Efficient Operation of Remotely Operated Vehicles as provided from the International Marine Contractors Associations (IMCA) for the Oceanology International Exhibition and Conference.

Before we start manufacturing we have made our custom design according to the required mission from the AUV and then we started looking for the material we are going to use according to competition standards we decided to use polypropylene as the main frame material since it have light weight and density of 946 kg/m^3 so we will avoid some buoyancy problems and also it's rigid it can sustain the pressure without adding extra weight. For the main hull we are using PA6 since it's rigid, lightweight, and manufacturable. For the torpedo we are 3D printing the torpedo with ABS plastic with light weight, so it will not affect the weight distribution or the control when it's fired, For the manipulator we are using a pre-isolated motor and a shaft attachment to transform circular motion into linear motion. Our priority is to make it as light as possible to get some bonus points and we are using pre-isolated parts to avoid making mistake in isolation or consume more time in reinventing the wheel. [42]

According to the competition standards we are following for the torpedo, it shouldn't exceed (51x51x152 mm) as dimensions and the weight shouldn't exceed 910 gm it should be 3D printed with the name of the team on the torpedo, they didn't specify for the launching system standards but we are using ready PVC pipes for the frame of the launcher and we are using commercial springs available at local suppliers but with a sufficient spring constant in order to fire for at least 1.5 meter underwater considering drag force, Following safety rules for the competition they will have technical inspection for the torpedo in order not to bruise a diver if it’s hit underwater from close range so they keep divers down safe. [43]

3.2.2 Electrical Subsystem

In this section we will introduce you to the standards we followed for our project which are the standards of The ROBOSUB competition and it will be related to the Electrical system.

The set of standards followed is:

a. The frequency used in the Pinger mission is from 25kHZ to 40kHZ so according to this frequency we will choose the hydrophone and the DSP board or the DAQ device.
b. The open-circuit voltage of any battery involved should not exceed 60VDC which limits our choices to at max 16 cells in series.
c. A kill switch should be added to the vehicle so that the divers can reach it easily just in case something bad happened.
d. Safety circuits are recommended to be used in order not to have damage in any part of the vehicle or not to damage a small device that let the vehicle survives under the water.
e. As we are going to use a Li-Po battery we should be able to provide an appropriate environment for it, so it can live longer.
f. The diameter of the wire should be calculated properly so that big amounts of current drawn wouldn’t cause a problem.

3.2.3 Software Subsystem

It’s always recommended to follow a certain standard style in the code writing and code commenting. Especially for big complex software system which is our case, first to make it readable for the developer and easy to debug, also to be easy for other developers to contribute in case of need to help or publishing the source code as an open source. So, we choose the following well known coding styles to follow in our software design.

a) Style guide for python code PEP 8

We are using the PEP 8 as our standard for writing codes in python, to make sure that our code does not have any naming conflicts with the language standard keywords

b) ROS developer's guide

For developing the main program on top of ROS, we are following the ROS developer’s guide as our standard, to maximize our software organization and make it possible for any future developer who want to exploit our code in his project.

c) ROS C++ Style Guide

C++ codes can be extremely messy if you are not following a certain style and will be sometimes hard for the same developer to read his code after a period. As well for the ease of debugging and have error free codes we are following the ROS C++ style Guide as our standard for developing C++ codes in our ROS packages

3.3. Design for Manufacturability and Assembly (DFMA)

During our design process, we followed some general principles in DFMA. These guidelines enabled us to reduce design time, manufacturing cost and effort and the ability to replace or modify any component by simply heading to the nearest CNC workshop. [44]

Table 3-7 Guidelines for DFMA [44]

Guideline	Implementation and advantages
Use standard commercially available components	We used commercially available thrusters, sensors, cameras and electrical components to reduce design effort and make sure that these components are quality controlled.
Use common parts across the proposed configuration	The following parts have been group manufactured / purchased: a) Thrusters b) Side Frame c) 3D printed adapters d) Motor sliders
Design for ease of part fabrication	All parts have been made to either be manufactured using a CNC machine or a 3D printer. This strategy enabled us to manufacture the whole chassis in less than a week.
Design the product to be foolproof during assembly	The UUV has a clear and an unambiguous process. It can easily be assembled by following the assembly sequence explained in chapter 4.
Minimize use of flexible components	There are no flexible components used which facilitates handling and assembling the vehicle.
Use modular design	The following components position can be adjusted according to the desired need: a) Surge thrusters can be moved vertically or horizontally. b) Heave thrusters can be moved vertically. c) The main hull can be moved horizontally

To keep track of our design efficiency, we calculated its actual DFA improvement as the vehicle is redesigned using the following equation: [45]

$$Actual\ Improvement = \frac{(Number\ of\ components\ in\ initial\ design)-(Number\ of\ components\ in\ redesign)}{Number\ of\ components\ in\ initial\ design}$$

[45] (3.1)

Table 3-8 Design for Assembly calculation

Design Configurations	Number of components in initial design	Number of components in redesign	Improvement (%)
1	-	28	-
2	28	34	-21.4
3	34	30	11.7
4	30	42	-40.0
5	42	37	11.9

The negative improvement between configurations 1 and 2 is due to the addition of more functions that were unnoticed during the first iteration. We tried to compensate for this regression during iteration 3 by designing more efficient parts, such as the gripper support, on which the sway thruster is now mounted. The improvement declines in iteration 4 is due to the addition of 3D printed parts, which increased the design rigidity and component mounting accuracy, but also increased the number of components. The overall number of components was reduced in the proposed configuration by 3D printing a single part for camera mounts instead of using three CNC-manufactured parts.

3.4. Design calculations

3.2.1 Mechanical Subsystem

3.2.1.1. AUV Calculations

To calculate the vehicles weight in water, we must subtract the buoyant force acting on the AUV from its mass. First, we obtained the overall volume of the vehicle from SolidWorks, then, using Archimedes principle, multiply it by the water density and gravity, which gives us the buoyant force. Next, we subtract this value by the mass, which is also obtained from SolidWorks, to get the vehicles weight in water.

Table 3-9 Buoyancy Calculation

Parameter	Method of calculation	Value
Weight on-shore	Obtained from SolidWorks	13.8 kg = 138 N
Total AUV Volume	Obtained from SolidWorks	About 0.0117 m^3
Density of water	-	1000 kg/m^3
Buoyancy Force	ρ x g x volume submerged	117 N
CG and CB separation	$CB - CG$	100.3 mm
Weight while fully submerged in water	Weight on shore – Buoyant force	138 – 117 = 21 N = 2.1 kg

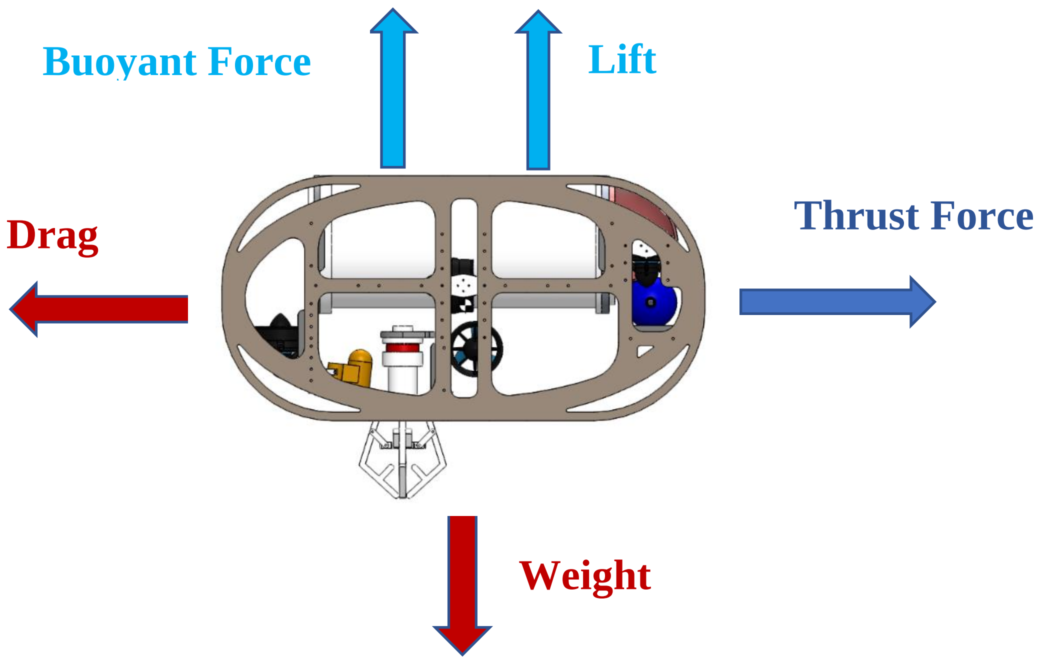


Figure 3-28 Forces acting on the AUV

For a condition where the AUV pitches at an angle of ϕ = 5°,

$$Total\ restoring\ moment = \sin(\phi).(CB - CG).Buoyant\ Force \tag{3.2}$$

$$= \sin(5)\ x\ (100.3)10^{-3}m\ x\ 117\ N$$

$$= 1.023\ N.m$$

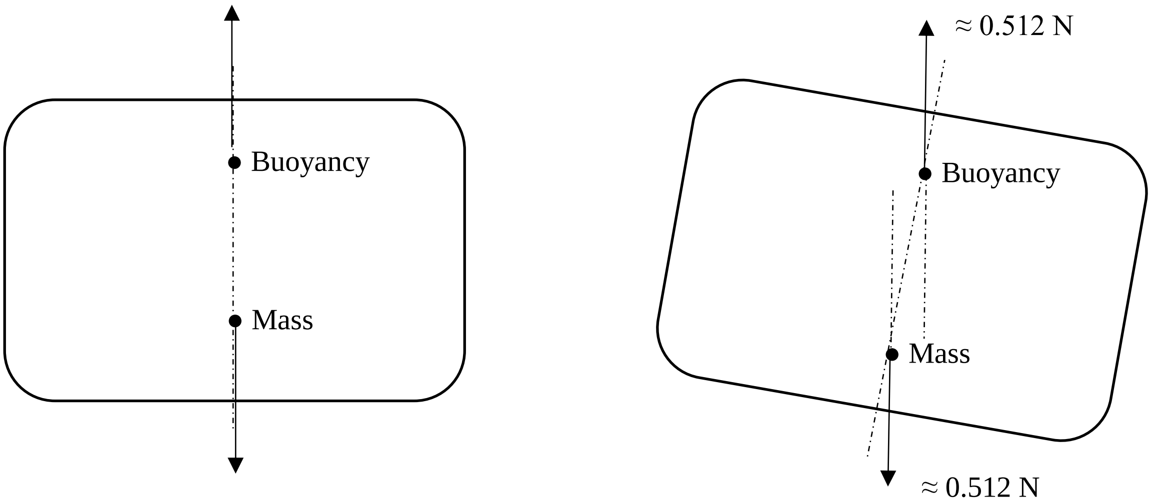


Figure 3-29 Left: Normal condition, Right: 10 °inclination condition

The following table describes the thrust value for each DoF:

Table 3-10 Thrust Calculation

Degree of freedom	Thrust x number of motors in the corresponding direction (N)	Maximum Thrust (N)
Surge forwards	2 x 51	102
Surge backwards	2 x 41	82
Heave upward	3 x 51	153
Heave downwards	3 x 41	123
Sway right	51	51
Sway left	41	41
Yaw	51 + 41	92
Positive Pitch	2 x 41 + 51	133
Negative Pitch	2 x 51 + 41	143
Roll	51 + 41	92

3.2.1.2 Torpedo calculations

Placing torpedo launchers in the AUV is a bit challenging since we need computer vision to know exactly where the torpedo is so we don't need to move much, we decided to place torpedo launchers below and above cameras since we have only two launcher so when the computer vision detects the firing place the AUV will move a little bit upward or downward to shoot this will make it easier for the control part, for the launcher itself we have used loaded spring equation to detect the amount of force we need to compress so we can achieve a desired distance through equation 3.3

$$F = -K.X \tag{3.3}$$

Where X (m) is the required distance while K ($\frac{N}{m}$) is the spring constant and F (N) is the force we need to calculate upon the required distance.

Considering the drag force will occur through friction with water is calculated by equation 3.4 (NASA)

$$D = C_d.A\frac{pv^2}{2} \tag{3.4}$$

Where D (N) is drag force, C_d is the drag coefficient, A (m^2) is the surface area, p is the density of the fluid, and v (m/s) is the velocity of the object.

And considering lift force with equation 3.5 (NASA)

$$L = C_l.A\frac{pv^2}{2} \tag{3.5}$$

Where L (N) is lift force, C_l is the lift coefficient, A (m^2) is the surface area, p is the density of the fluid, and v (m/s) is the velocity of the object.

And the total force affecting the firing distance will be calculated using equation 3.6

$$\sum F = T + mg + L + D \tag{3.6}$$

Where ∑F is the total force on the torpedo, T is the trust, m is the mass, g is gravity, L is lift, and D is the drag force.

To calculate the drag coefficient (C_d) we rearrange equation 3.2 to become equation 3.7

$$C_d = \frac{2D}{\rho v^2 A} \tag{3.7}$$

Substituting the following values in (eq 3.5): D= 0.0105 N, ρ=1021 kg/m^3, v=0.5 m/s, A=0.0002715 m^2

Results with a drag coefficient: C_d=0.3

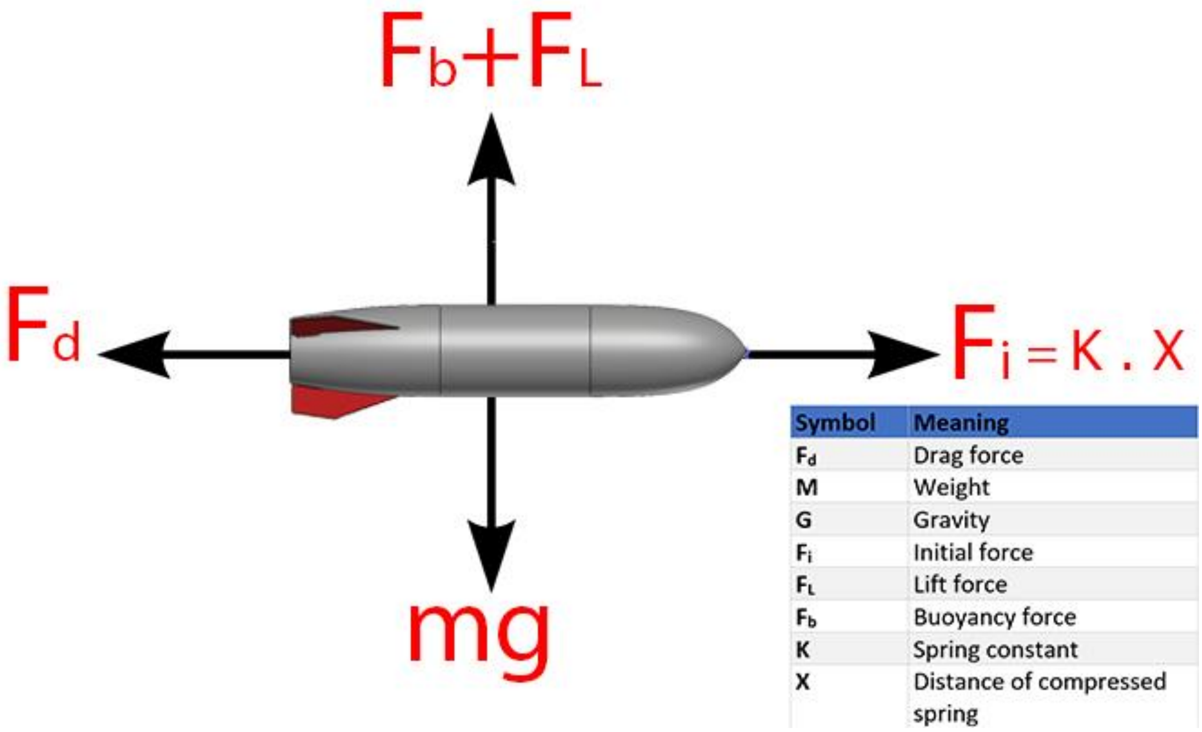
For the torpedo design we are using Archimedes principle to calculate the weight of the torpedo underwater for the projectile motion equation

Buoyancy equations for submerged object (equation 3.8)

$$Fb = V * \rho * g \tag{3.8}$$

where, Fb is the buoyancy force affecting the object, V is the volume of the object, ρ is the density of water = 1021 kg/m^3, g is the gravity which is 9.807 m/s^2

so, by using these equations we are designing our torpedo launching system to achieve desired range. And the free body diagram of the torpedo is shown as follows



Symbol	Meaning
F_d	Drag force
M	Weight
G	Gravity
F_i	Initial force
F_L	Lift force
F_b	Buoyancy force
K	Spring constant
X	Distance of compressed spring

Figure 3-30 Forces acting on the torpedo

3.2.2 Electrical Subsystem

In this section we are going to present the calculations needed to build and design the system according to some theoretical background. Plus, it will be about the Electrical subsystem and these calculations are very important because it’s dangerous to power up your system without them.

3.2.2.1 Battery Calculations

After some calculations and decisions, we tend to use a battery of the type Li-Po and with 4 cells in series to give a total nominal voltage of 14.8VDC (3.7VDC each) and a capacity of 10Ah to power up the motors without the need of voltage regulators and to be on for an enough time.

Diving Time Calculation will be done using equation 3.9 to determine the working time of the vehicle:**Invalid source specified.Invalid source specified.**

$$\text{Time} = \left(\text{Battery Capacity} * \frac{\text{Battery Discharge}}{\text{Average Amp Draw}}\right) * 60 \tag{3.9}$$

Battery discharge corresponds to 80% of the battery to be used because it’s not encouraged to discharge the Li-Po battery fully, so it doesn’t damage or reduce the efficiency of the battery. Where battery capacity is 10Ah in our case and the average amp draw is 25A at max. So, using this information we will find that the diving time is 19.2 minutes.

3.2.2.2 Wire Calculations

As we are going transmit electricity through the wires the need of a pre-determined diameter wires arises. In addition, the bigger the diameter is the more current can flow through it.

To calculate the diameter of the wire we should consider its resistance, and that resistance should be very close to zero to act as a short circuit and then the whole current can flow.

To calculate the diameter of the wire we will use equation 3.10

$$R = \rho * \frac{l}{A} \tag{3.10}$$

where ρ: resistivity, l: length of the wire and A: cross sectional area

And we will assume the resistance to be 0.2 ohms and the resistivity of the copper since most of the cables are made by copper and it is equal to 1.72*(10^-8) ohms and the length is assumed to be 50 meters long and the area of the wire is calculated using equation 3.11

$$A = \frac{\pi}{4} * d^2 \tag{3.11}$$

where d is the diameter of the wire in meters and A is the area in meter squared.

After all these assumptions, the diameter of the wire will be 2.34m.

3.5. Cost analysis

The quantity, cost and shipping method are described in the following table. The shipping cost is TBD

No.	Part no.	Description	Model	Vendor	Quantity	Price	Total USD
1	CC.01.M.I.ACF	Aluminum cylinder flange	Al-6063	Engineering Workshop	2	228	456
2	CC.01.M.I.AHC	Aluminum Hull cap	Al-6063	Engineering Workshop	2	148.2	296.4
3	CC.01.M.B6	6mm bolt	LN type	Sennaroglu	20	4.275	85.5
4	CC.01.M.I.PVC	PVC tube	20x50 cm	Engineering Workshop	1	28.5	28.5
5	CC.01.M.I.HDPE	HPDE	25 cm	Engineering Workshop	3	5.216666667	15.65
6	CC.01.M.I.O	O-rings	-	Sennaroglu	8	19.95	159.6
7	CC.01.M.G	Grease	Silicon grease	Senneroglu	1	8.55	8.55
8	N.A	3M marine silicon	PN08019	amazon	1	28.5	28.5
9	CC.01.I.PG7	PG7 gland	Aluminum PG gland	elektrokur	8	2.85	22.8
10	CC.01.I.PG9	PG9 gland	Aluminum PG gland	elektrokur	4	3.135	12.54
11	CC.01.I.PG11	PG11 gland	Aluminum PG gland	elektrokur	4	3.42	13.68
12	N.A	Manufacturing AL flange	Custom design	Engineering Workshop	2	45.6	91.2

13	N.A	Manufacturing AL caps	Custom design	Engineering Workshop	2	28.5	57
14	CC.01.M.CH.CHS	HDPE sheet	1x0.75 m	Engineering Workshop	2	142.5	285
15	CC.01.M.B4	4 mm st steel bolts and nuts	Philips type	Sennaroglu	80	0.912	72.96
16	CC.01.M.AT	Acrylic tube	15 cm x 45 cm	Engineering Workshop	1	171	171
17	CC.01.M.I.PHC	Plastic hull cap	Custom design	Engineering Workshop	2	34.2	68.4
18	N.A	CNC cutting HDPE	Custom design	Engineering Workshop	1	369.5	369.5
19	CC.01.E.BM	Bilge motor	500 GPH Bilge Pump	Al-Shorok company	6	57	342
20	CC.01.E.S.CM.B	HD isolated camera	-	Al-Shorok company	1	85.5	85.5
21	CC.01.E.P.PWC	Power cable 20m	-	Al-Shorok company	1	114	114
22	CC.01.E.C.ETH	Ethernet cable	High speed ethernet	Al-Shorok company	2	22.8	45.6
23	CC.01.E.HB	H-bridge	Cytron	Al-Shorok company	3	33.06	99.18
24	CC.01.E.AM	Arduino mega	Uno-3	Al-Shorok company	1	38.475	38.475
25	CC.01.E.AN	Arduino Nano	-	Al-Shorok company	1	22	22
26	CC.01.E.S.CM.A	360 isolated camera	-	Al-Shorok company	1	102.6	102.6

27	CC.01.E.S.MP	Asus mini PC	ASUS UN68U-M026M	yiwu younus	1	679.25	679.25
28	CC.01.M.D.T2.X	T200 thrusters	T200	BlueRobotics	8	196.5	1572
29	CC.01.M.I.CP.X	Bluerobotics connectors + leak sensors	-	BlueRobotics	1	312	312
30	N.A	VAT	-		1	152	152
31	CC.01.M.FR	plexiglass	10 mm thickness plexiglass	Er-reklam	1	300	300
32	CC.01.E.FC	Pixhawk flight controller	-	M-robotics	1	250	250
33	N.A	Shipping	-	DHL	1	650	650
34	N.A	Overhead	-		10%	700.7	700.7
	Total						**7708.9**

Table 3-11 Bill of Materials

Chapter 4 – MANUFACTURING PLAN

4.1. Manufacturing process selection

Table 4-1 discusses the process of manufacturing each part. It also includes the suppliers and their locations.

Table 4-1 Manufacturing Plan

No.	Part number	Part name	Vendor	Machine	process
1	CC01.M.CH.HDPE	Frame	Local suppliers (Egypt)	a) CNC	a) Main frame will be cut on CNC machine b) Assembly is done by screws and bolts
2	CC01.M.G	Gripper		b) N.A	c)
3	CC02.M.T.T	Torpedo	Local suppliers (Cyprus)	c) 3D printer d) Hacksaw	d) By fixing the spring at the end of a PVC pipe and attaching a latch to the spring our launcher will be ready e) Torpedo's will be 3D printed according to the CAD design and the launcher will be ready
4	CC01.M.I.HUL	Isolation tube	Local suppliers (Egypt)	e) Lathe machine	f) It will have 3 main parts g) Al 6063 cap made on lathe machine h) The connectors end cap which will require lathe machine in shaping and drilling 16 holes inside this cap to connect cables i) For the main part it will be fabricated on lathe machine according to the given design
5	N.A	Isolation technique	Local suppliers (Cyprus)	f) N.A	j) Using O-rings for the plastic end cap k) Using marine silicon around the caps l) Using grease around the end caps m) Using 3M compound those techniques will be applied consequently to achieve maximum isolation

Table 4-2 elaborates the steps to assemble each mechanical system.

Table 4-2 Assembling Plan

No.	Part number	Part name	Assembling
1	CC01.M.CH.HDPE	Frame	a. Screws will be used to mate between side Al 6063 supports and the main frame b. The hull will be mounted after assembling it c. Motors will be fixed in their places using bolts and nuts only d. Torpedoes will be mounted using PVC pipe hanger which will be directly attached to the main chassis e. The gripper will be fixed.
2	CC01.M.I.HUL	Hull	a. The hull will be assembled by closing the end caps and adding isolating material
3	CC02.M.T.T	Torpedoes	a. Torpedoes will be assembled by soldiering the spring to the bottom of a PVC pipe and attaching a latch to the spring, so it can be reloaded and fired b. The torpedo will be 3D painted and a metal rod will be added inside torpedo to achieve desired weight.
4	CC01.M.G	Gripper	-

4.2. Detailed manufacturing process

4.2.1. Procurement and Shipping

After selection of material and approving the design and writing down most of the part list and decided the manufacturing way we decided to order our parts from Egypt since we have a lot of options and we will send the designs to the workshops there so we can have our parts ready there, we have an advantage by procurement from Egypt since it's much cheaper than Cyprus and also good equipment and well working technicians. So, the rest is just assembling parts here and testing.

All the components will be sealed and boxed in Egypt and it will be shipped through cargo, this will add to the cost but still cheaper than local suppliers and this was the best option the team agreed on.

4.2.2. Detailed Manufacturing

Our AUV is going to be built using a wide variety of manufacturing techniques, we are going to use a wide range of measuring devices to ensure compliance with our rigid model, including calipers, rulers, squares, level and measuring tape. Using lathe machine to make our custom designed isolation tube with two caps at the ends, one cap is made from Al 6063 acting as a heat sink and the other cap Is made from plastic which will have 16 hole where we are going to use penetrators to connect cables without water leakage , using O-rings around the end caps is the first stage of isolation followed by 3 other stages which are as follows

a) Marine silicon and silicon grease to the end caps will help providing maximum safety from leakage
b) 3M compound which is the final stage where we add it on the edge between the end caps and the main isolation tube
c) Isolation tube material is mainly BA6 plastic which will be manufactured using lathe machine according to the design and by the help of workshop technician.
d) 3D printing the external shell to benefit maximum from the aerodynamics without adding much weight in addition to covering to the main parts and giving a good shape to the AUV.
e) CNC machine will be used to cut our main frame according to the provided design, the frame is made from polypropylene with some side supports made from Al 6063 and this Al 6063 is cut by normal saw.
f) Loaded spring provided at local suppliers will be used to assemble the torpedo launcher with a bilge motor to remove the latch allowing the torpedo to be fired to the target.
g) Since we are using CNC and 3D printing techniques in building our AUV most of our manufacturing will be assembling parts with screws and screwdrivers, and it will not take a lot of time according to the Project Timeline given in Appendix E.

We will start manufacturing process by assembling the main frame that we have cut on CNC and mounting the main hull on the frame and putting some weights inside (dummies) and start testing the isolation technique and the dynamics of the AUV, next step is mounting the thrusters, gripper and torpedoes on the chassis without removing dummies and start testing the motors stability and control. Last step is to mount all parts inside the isolation tube and make sure every part is working perfectly then we can proceed to the next step which is the most important one (Testing), before moving to testing we will make sure every single point is working perfectly without any interactions with other systems.

4.2.3. Assembly Steps

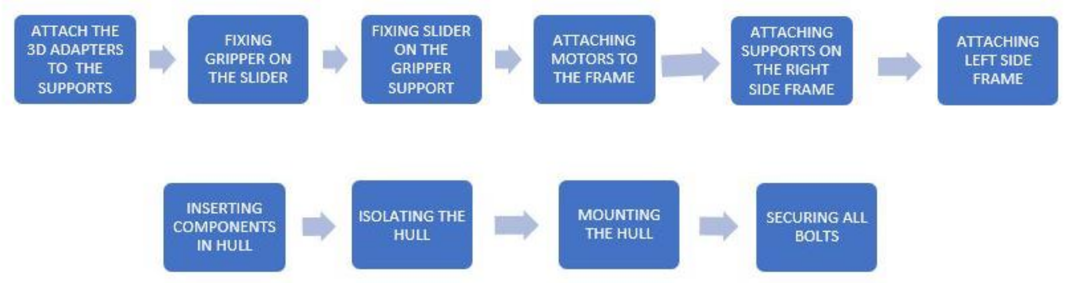


Figure 4-1 Assembly Sequence

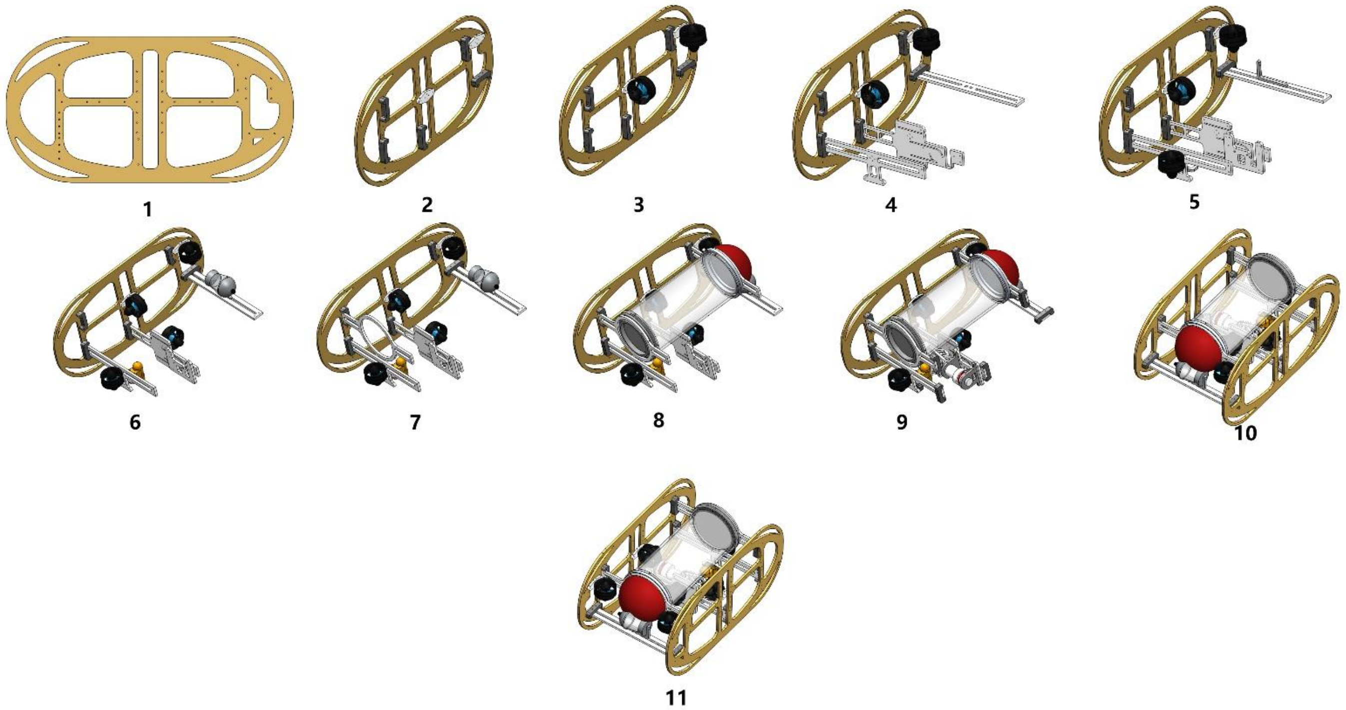


Figure 4-2 Assembly Steps Illustration

Chapter 5 - PRODUCT TESTING PLAN

5.1. Failure Mode and Effects Analysis (FMEA)

The final design should be tested after manufacturing to ensure its safety and quality, also all parts should be tested to ensure that they function as intended, after that all sub-systems will be tested, and finally the complete vehicle will be tested to verify its ability to perform the intended objectives, the test are performed to ensure that none of the elements has failed and they have achieved their intended functionality, table 5-1 provides a Failure Mode and Effects Analysis (FMEA), it also includes the Risk Priority Number calculations.

Table 5-1 Failure Mode and Effects Analysis

#	Part number	Function Effected	Potential Failure Modes	Potential Failure Effects	Potential Causes of Failure	RPN = Severity*Occurrence*Detection	Recommended Action
1	CC01.M.I	Isolation	Water Leakage	Electric power circuit Short, Breaking internal components	Impact to the hull, Improper end cap installation, penetrator breakage	10*2*3=60	Detect failure using leak sensor and cutoff power.
2	CC01.E.D.T2	Thrust	Thrusters not working	Vehicle unable to move, Vehicle unable to stabilize	Empty battery, Disconnected power cable, ESC not working, Control computer disconnected	8*2*1=16	Check power levels and connections proper installation
3	CC01.E.C.PX	Control	Uncontrollable behavior	Unable to return to stable position,	Bad IMU readings, Broken thruster, Broken ESC	7*2*1=14	Kill switch then remove the vehicle from water

				Moving in the wrong direction			and check all thrusters and sensors.
4	CC01.E.C.PX		Extreme overshoot	Unable to reach and stop at destination	Poorly calibrated Controller and sensors, High latency in communication	5*2*2=20	Check Controller and sensor calibration.
5	CC01.E.S.BR	Depth control	Wrong depth	Unable to hit expected depth	Broken depth sensor	6*2*3=36	Add redundant depth sensor, test and calibrate depth sensors
6	CC01.E.S.BR		Fluctuating depth	Unable hold depth	Poorly calibrated Controller and depth sensors, High latency in communication	5*2*2=20	Check Controller and depth sensor calibration.
7	CC01.M.G	Gripper	Not actuating	Unable to hold or release object	Power disconnect, Disconnected controller, Broken actuator	7*2*1=14	Check actuator, check power, and check connection to controller
8	CC02.M.T	Torpedo	Not firing	Unable to fire torpedo	Power disconnect, Disconnected controller, Broken actuator, stuck in firing tube	6*3*1=18	check if stuck, Check actuator, check power, and check connection to controller.
9	CC02.M.T		Missing Target	Over or under shooting target	Improper release, bad torpedo design, bad alignment with target,	5*2*2=20	Test torpedo and firing mechanism design, test and calibrate vision alignment.

					vehicle unstable while firing		
10	CC02.M.M	Mark Dropper	Not releasing	Unable to drop marker	Power disconnect, Disconnected controller, Broken actuator, stuck in tube	6*2*1=12	check if stuck, Check actuator, check power, and check connection to controller.
11	CC02.M.M		Missing Target	Over or under shooting target	Improper release, bad alignment with target, vehicle unstable while dropping	5*2*2=20	Test dropper mechanism design, test and calibrate vision alignment.
12	CC01.E.P.PD B	Power distribution	Power cutoff	Data loss, vehicle sink	Empty battery, Broken battery, Broken PDB, Disconnected battery	8*3*2=48	Check battery, check PDB, Check Connection wires
13	N.A		Power surge	Burning electrical components	Miss designed power distribution system, Broken PDB.	9*2*3=54	Test and verify power distribution system, check PDB.
14	CC01.S.AS	ROV control	Control loss	Vehicle sink	Broken control pad, Disconnected tether	7*2*1=14	Check tether, Check control pad
15	CC02.S.AS	AUV control	Unstable navigation	Missing mission targets and objectives	Bad sensor and camera data, software bug or crash	7*4*2=56	Extensively test and review software layer, check all sensor connection and functionality
16	N.A		Wrong instructions	Torpedo and dropper improper release,	Bad sensor and camera data, software	7*3*3=63	Extensively test and review software layer,

				miss executing a mission	bug or crash, poorly designed mission plan (State Machine)		check all sensor connection and functionality.
17	CC02.S.CV	Vision	Loss of Vision	Loosing direction, unable to identify mission objectives	Disconnected Camera, Software crash, processing pc crash	8*2*1=16	Check cameras connection and functionality, check computer and software layer.
18	N.A	Sonar localization	Signal loss	Unable to locate target	Broken hydrophone, Broken DAQ or DSP board	5*2*1=10	Check hydrophones, Check DAQ or DSP board
19	N.A		Bad Signal	Identifying wrong target	Signal noise, Low quality hydrophones and DAQ or DSP boards.	5*2*1=10	Test and verify hydrophone and DAQ or DSP sufficiency, eliminate possible noise sources
20	CC02.S.RS	Data Logging	Data Loss	Losing some or all sensor data during testing and operation	Code error, hard drive failure, computer crash, disconnected sensor.	2*2*1=4	Check hard drive and computer, test and review software layer

5.2. Verification of the objectives of the project

5.2.1. Phase 1

Our overall objective was to build an AUV capable of competing in RoboSub competition. The capstone objective was to design, manufacture, test and validate prototype 1, as shown in the table below.

Table 5-2 Phase 1 obtained results

#No.	Part Number	Test Name	Feature\Part	Equipment	Standards	Test Description	Results
				Mechanical Subsystem			
1	CC01.M	Inherent Stability	UUV Cg\Cb	Pool	N.A	The UUV is placed in the water, to see if it will remain stable.	The vehicle was inherently stable without external forces
2	CC01.M.CH	Chassis	HDPE	Pool		The main challenge is the on-shore structure integrity, as the forces acting underwater are diminished.	The frame was rigid during transportation and handling
3	CC01.M	Restoration Forces	UUV cg\cb	Pool	N.A	A force is applied to the UUV to test its restoration capability and time	The restoration force was slightly more than calculated, it is planned that prototype 2 shall has smaller separation between the Cg and Cb
4	CC01.M.I.HUL	Isolation	Hull	Leak Sensor	IP6X	The UUV is left in the water for an extended period with a leak sensor placed inside the main Hull to detect any water isolation defects	After various tests, our isolation method was validated. Our future plan was to increase 1 more isolation stage on the caps
5	CC01.M.D.T2.X	Motor Configuration	Bluerobotics T200	Pool		The motors were set to maximum thrust to validate that the vehicle moves in a straight line and with sufficient speed	The vehicle performed as expected without the aid of the software stabilization.

6	CC01.M.G	Gripper mechanism	manipulator	N.A	N.A	Testing the gripper is capable of holding objects of different sizes	The gripper was able to handle objects of different shapes.
				Electrical Subsystem			
7	CC01.E.D.T2	Thrusters off-board	Thrusters	Multimeter	N.A	Thruster are tested to confirm they function properly before they're installed on the UUV	At first, each thruster was tested alone and the current measured for each to be at max 3A DC (Note: it was tested using Arduino and Pixhawk to provide the motors with PWM signals)
8	CC01.E.D.T2	Thrusters on-board	Thrusters	N.A	N.A	Thrusters are tested to confirm they were installed properly on the UUV	After installing all the components on the vehicle each motor was tested alone and then together with the corresponding motor for a special movement to check functionality (Note: all movements and directions were tested and verified)
9	N.A	Power Supply	Power Supply	PC Power Supplies	N.A	Main Power Supply tested to certify it delivers the required voltage and power the vehicle needs	Connecting five PC power supplies allowed us to have 1.5 kW of power at 12VDC and they were connected in parallel to give full power. In addition, after the vehicle was completed the power supply was tested by pulling the max current the vehicle needed which was about 25A DC
10	CC01.E	Electrical circuitry of Components	Electrical System	All Components	N.A	All of the components connected together to justify the functionality of each component	This kind of test has been done in two ways which are off-board and on-board

							tests, and both were successful
11	N.A	Safety	Kill Switch	PixHawk	IEC 62133	Testing the kill switch functionality	By applying a short-circuit condition to Pixhawk's kill switch terminals and checked the output of the motors' terminal which were off even if a signal was present at the input
12	N.A	Circuit Connectivity	Electrical Sub-system	Connection tester circuit	NFPA 496,NFPA 70	Verifying that all electronic components are connected properly	This was done by using a Multimeter to check all connections and make sure no short-circuit is present
Software Subsystem							
13	CC01.S.AS	PID Stability	PID\IMU	Pool	N.A	A force is applied to the UUV to test the PID controller response	The vehicle maintained stability whether there is an external force or not.
14	CC01.S.C	Communication	Communication between Vehicle and surface station	Vehicle Ethernet Power supply		Establishing an SSH connection and receiving vehicle diagnostic and video stream of vehicle cameras.	The connection was stable and uninterrupted, but the bandwidth was limited causing some lag in the video stream.
15	CC01.S.AS	PID Depth-hold	PID\Pressure sensor	Pool Depth Sensor	N.A	A force is applied to push the UUV down to test the PID controller response and depth hold capabilities	Vehicle behavior was satisfactory with a small error. After applying an external force, the vehicle kept its current depth away from external forces.
16	CC01.S.RS	Maneuvering	AHRS\IMU	Pool	N.A	All the maneuvering moods are tested to verify they function properly	Vehicle showed sufficient maneuverability ability.
17	CC01.E.S	Sensor Readings	Sensors	Intel NUC	NISTHB 157	Verifying All sensors readings are reaching the main computer	Sensors provided reliable readings.

18	CC01.S.RS	Thrusters direction (Dry)	Thrusters	Thrusters Surface computer	N.A	Ensuring all Thrusters are mounted in the correct orientation and thrust in the proper direction.	thrusters 1, 2, 5 needed a reversed polarity.
19	CC01.S.RS	Thrusters speed control (Dry)	Thrusters	Thrusters Surface computer	N.A	Testing the electronic speed controllers (ESCs) for each Thruster individually by giving arbitrary speed values.	All thrusters operated as expected.
20	CC01.S.RS	Save vehicle state	Save_vehicle_state.py (ROS node)	Vehicle Surface computer	N.A	By calling this service the current state of the vehicle will be saved including (depth, heading, position and missions finished)	The service tested and operated as expected.
21	CC01.S.RS	MAVROSService caller	MAVROSService_caller.py (FlexBe state)	Vehicle Surface computer	N.A	Calling different mavros services through the state.	The state worked as required
22	CC01.E.S	Sensor Calibration	Sensors	QGround Control (Software)	NISTHB 157	Calibrating sensors, and then test their output	Sensors were calibrated, and then tested verifying their accurate output.
23	N.A	Communication	Communication between Vehicle and surface station	Router/ Ethernet tether	N.A	Establishing a SSH connection and receiving vehicle diagnostic and video stream of vehicle cameras.	The connection was stable and uninterrupted, but the bandwidth was limited causing some lag in the video stream.
24	CC01	ROV mode	Complete Prototype 1	Pool	N.A	Controlling the vehicle by a pilot, to navigate a course and perform tasks.	The pilot was able to navigate the course and complete the tasks

5.2.2. Phase 2

Table 5-3 Phase 2 obtained results

#No.	Part Number	Test Name	Feature\Part	Equipment	Standards	Test Description
			Mechanical Subsystem			
1	CC02.M.T.TL	Torpedo mechanism	Torpedo Firing	Pool	N.A	Testing the buoyancy force against weight and testing the projectile range
2	CC02.M.MD	Mark Dropper	Bilge motor + Gears	Pool	N.A	Ensure the mechanism is capable of dropping the golf ball precisely in the designated area.
			Electrical Subsystem			
3	CC02.E.P.BT	Batteries	LI-PO Batteries	N.A	N.A	Batteries are tested to confirm they deliver the required power the vehicle needs
4	N.A	Power	Power Sub-system	Voltage Checker	IEC 62133	Voltage checker tested to confirm it gives correct values about the status of each battery
5	CC02.E.S.HPH	Hydrophone	Hydrophone	Oscilloscopes	IEC 60500	Testing Hydrophone array functionality
6	CC02.E.C.FPGA	FPGA	Arty A7	Laptop	N.A	Test how fast the response is for the board and to measure the temperature of the chip
7	CC02.E.C.ADC	ADC	Pmod AD1	Arty A7	N.A	Test the resolution and speed of processing of the board
8	N.A	Pinger	Pinger	Oscilloscope	N.A	Testing the output frequencies of the pinger
			Software Subsystem			
9	CC02.S.RS	Autonomous Navigation	Tracking camera	Pool Tracking camera PixHawk Thrusters	N.A	The system is a given a pre-set goal point in space and observe the vehicle behavior to reach that point. In addition, calculating the error to ensure it is in the acceptable band

10	CC02.S.RS	Localization	Localizing the vehicle in 3D space	PixHawk Tracking camera (visual odometry)	N.A	Fusing odometry values coming from PixHawk and Intel camera into an Extended Kalman filter
11	CC02.S.RS	AUV startup	Automatic launch of vehicle systems.		N.A	Testing autonomous launch sequence of the vehicle systems
12	CC02	Autonomous Vehicle	Complete System	-	N.A	Test complete system inside the pool powered by batteries
13	CC02.S	AUV startup	Automatic launch of vehicle systems.	Pool		Testing autonomous launch sequence of the vehicle systems
14		AUV navigation	Autonomous navigation	Pool		Autonomous navigation of the vehicle using a per-defined plan.
15	CC02.S.CV	AUV vision	Object detection	Pool	N.A	A gate was placed in the pool to test the vehicle ability to detect it.
16	-	AUV guidance	Autonomous navigating to a specific location	Pool		Finding a target and navigating towards it and then returning to the original position
17	-	AUV mode	Complete Prototype 2	Pool	N.A	Controlling the vehicle by a pilot, to navigate a course and perform tasks.
18	CC02.S.RS	Mechanisms	Mechanisms.py (FlexBe state)	Vehicle Surface computer	N.A	Dropping markers, firing torpedos, holding and releasing objects using the manipulator.
19	CC02.S.RS	Align with gate	Align_with_gate.py (FlexBe state)	Vehicle Surface computer	N.A	Aligning the vehicle with a color-coded gate.

Chapter 6 - RESULTS and DISCUSSIONS

6.1. The results

6.1.1. Assembly and Dry Tests

Prototype 1 was capable of performing the given missions as expected. The proposed design configuration was able to maneuver efficiently underwater without any deviations. It was also inherently stable and was able to restore its orientation without software interference. The vehicle's buoyancy was set to critically floating by adjusting the buoyancy force to be slightly more than the vehicle's weight, which eases the vehicle's retrieval in case of an emergency shutdown. In addition, the isolation method used proved to be reliable as the vehicle was tested multiple times without leaks.

First, we exported the designed parts as DXFs and sorted them on AutoCAD to be cut on a laser CNC machine. The following figures shows the manufacturing process of the chassis.

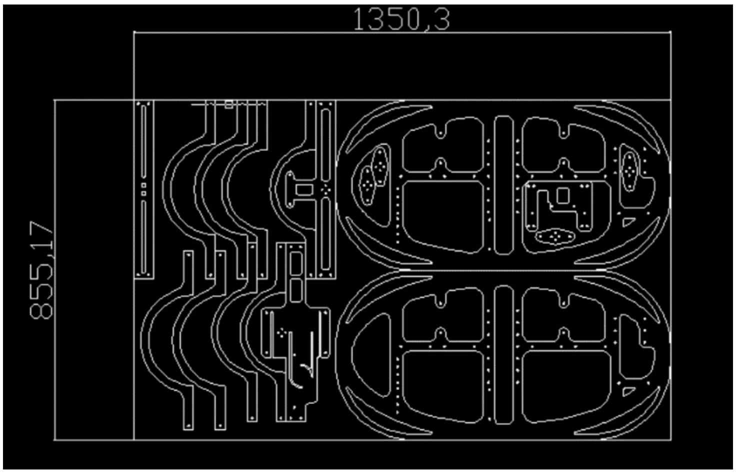


Figure 6-1 DXF File

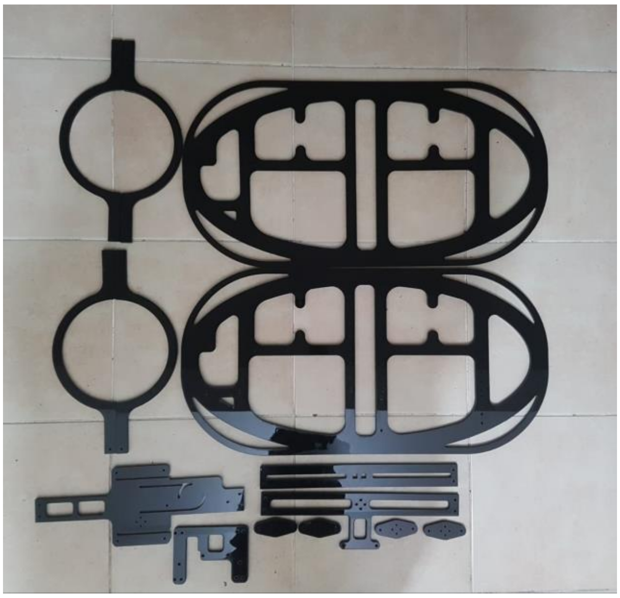


Figure 6-2 Chassis parts before assembly

Next, the designed tube was manufactured and shipped from Egypt and was ready to be assembled and fitted into the chassis.

Figure 6-3 a) manufacturing the isolation hull

Figure 6-4 b) Aluminum flange and HDPE endcap

Figure 6-5 c) Preparing the components to be shipped

As the testing scheme has two different stages, all the electrical components were tested in both stages.

The first stage was to have the components tested alone, and that was done on each of the following:

a) T200 Thruster

Before installing the motors on the vehicle, we needed to measure the current drawn by the motors when full speed is applied, to design the power system accordingly. Plus, we needed to check what signal is needed to get the direction of the motor. The test of the T200 motor alone which results in a satisfactory value of the current which was 3A DC at 12VDC. (Note: the controller used in the test was Arduino UNO)

b) Power Supply

After connecting the five PC power supplies together to construct the main power supply, a test was conducted to confirm the voltage and power output of the power supply (1.5kW at 12VDC). Furthermore, after this test was done a plug was chosen to be used for ease and safety which can handle up to 30A DC.

Figure 6-6 Main Power Supply

Figure 6.2 shows the main power supply after installing the plug. (Note: the five PC power supplies are inside the housing and nothing else is there).

c) Bilge Motors

This test was applied by the help of the H-bridge used to check the direction and speed control of the motors. In addition, an external propeller was added to make sure that the torque of the motor is enough to control the parts.

d) Pixhawk

After taking the first three tests we needed to go further for bigger tests, and here the test takes place to make sure that the controller delivers the right values to the motors.

e) Mini-PC

The main controller of the vehicle is the mini-PC, and in its first test we had a problem where we needed to automate the mini-PC to turn on whenever it takes power. A solution to this issue was by adding a Relay module to short the two pins of the push-button of the mini-PC for two seconds.

The second stage was to test the overall system and the results were as expected since we have done the individual tests for each component. However, a slight issue we faced which is that the mini-PC was turning off automatically since there was a non-stability of the voltage delivered to it, and that was solved by adding a DC-DC Boost Converter to provide the mini-PC with a stable 12VDC.

The Following images shows the electrical circuitry while being assembled and chemically isolating the hull.

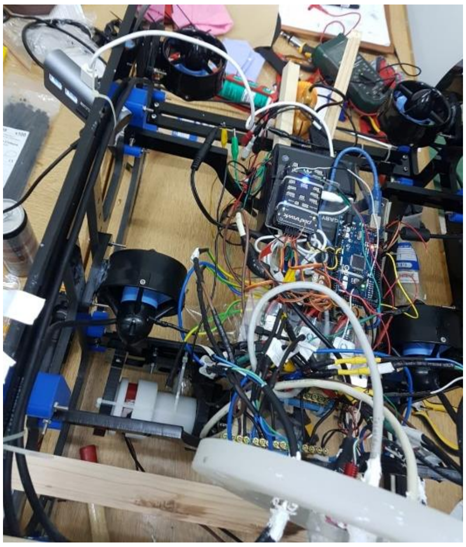


Figure 6-8 Electrical circuitry assembly

Figure 6-7 Applying chemical isolation

The control software showed a satisfactory success with the ability to self-level the vehicle, maintaining a certain depth and stabilizing vehicles' heading. Our autonomy software is based upon the opensource tools such as, ROS, ArduSub, FlexBe and OpenCV. Making use of these software tools provided the system the ability to be modular and functional.

Prototype 1 of the UUV has been successful in achieving all the intended ROV functionality almost perfectly, and it served as good first step in AUV mode, achieving some functionalities with levels of success and accuracy, but it still leaves a big margin for improvement and optimization. Some of the shortcomings in AUV mode will be improved through code improvements, while others such as the accuracy of the vision system will also require better hardware such as the use of a higher resolution and color accuracy camera, also navigation and guidance will be improved by the use of stereo cameras to obtain depth information of the detected targets and SLAM tracing cameras to provide visual odometry to help the vehicle keep track of its global position.

6.1.2. Wet Tests.

Finally, after assembling the vehicle, the tests were performed at the EMU Beach Club. The following Figures shows the finished product.

Figure 6-9 Different views of Prototype 1 ROV CC01

Next, we started the initial software simulations testing and verification

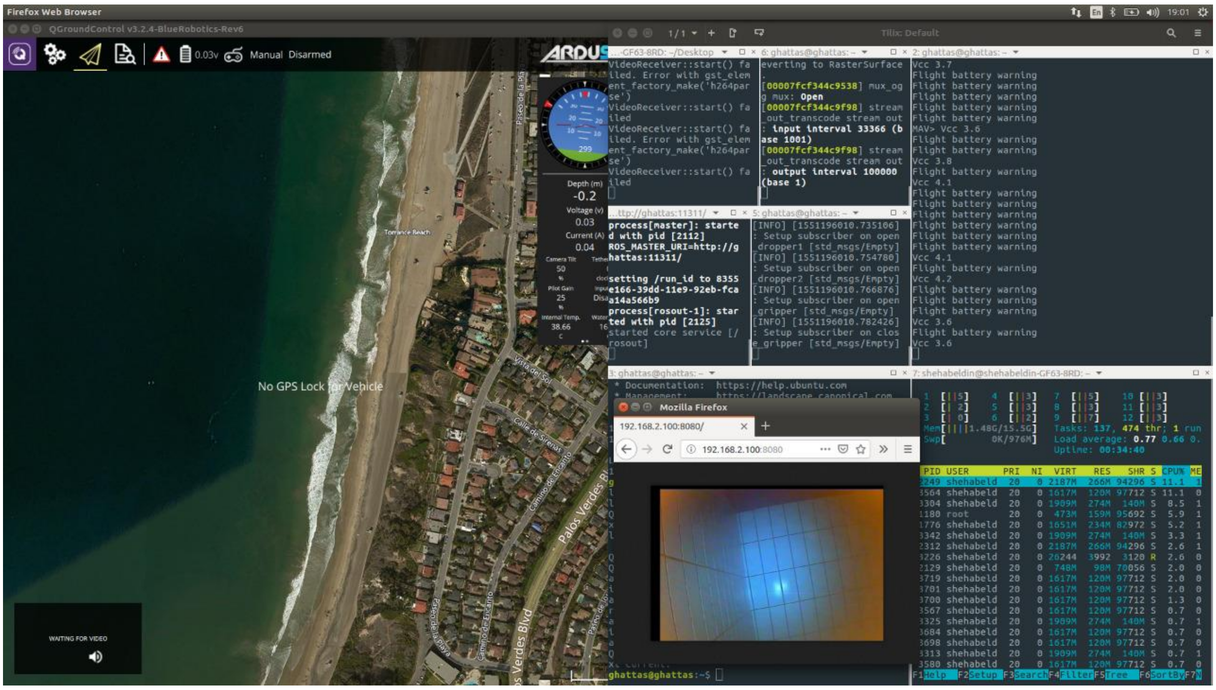


Figure 6-10 Early software testing and verification

We successfully received a clear and stable image from the on-board camera. The figure below shows the software system under operation with a live feed from the camera

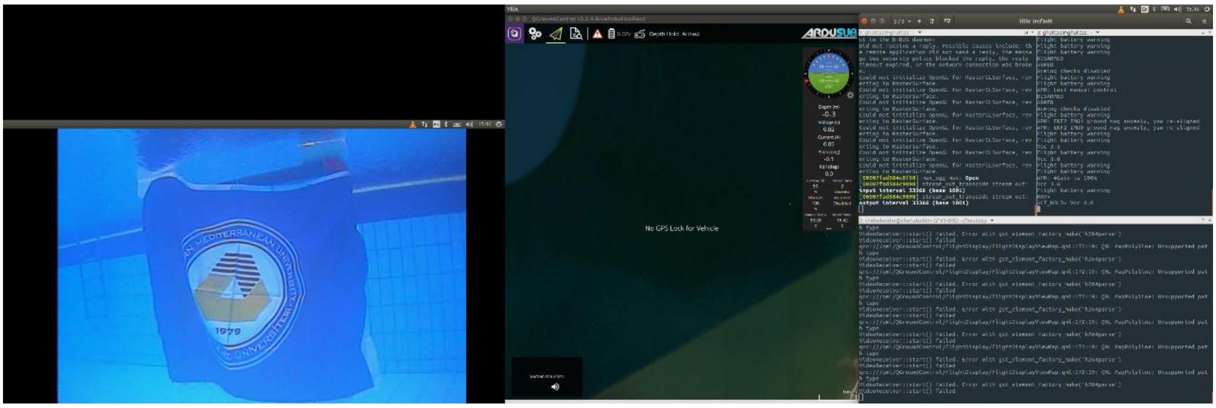


Figure 6-11 Tuning and testing the live feed from the camera through the Ethernet connection

After performing the basic movement and isolation tests explained in chapter 5, we proceeded to test the vehicle's capability of maneuvering through a gate and testing its stability.

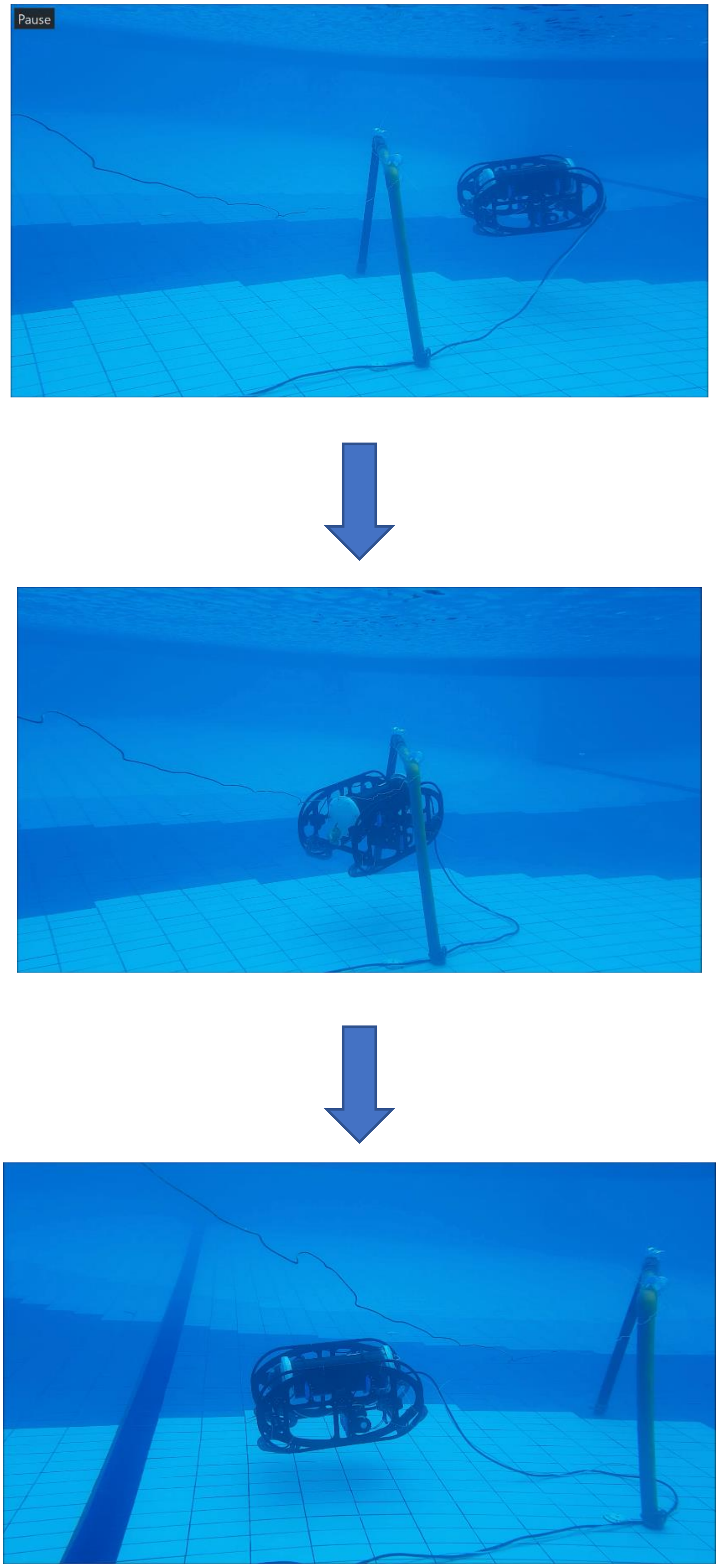


Figure 6-12 Prototype 1 passing through the gate sequence

After successfully completing Prototype 1 ROV CC01, we started testing the initial image processing system of prototype two AUV CC02.

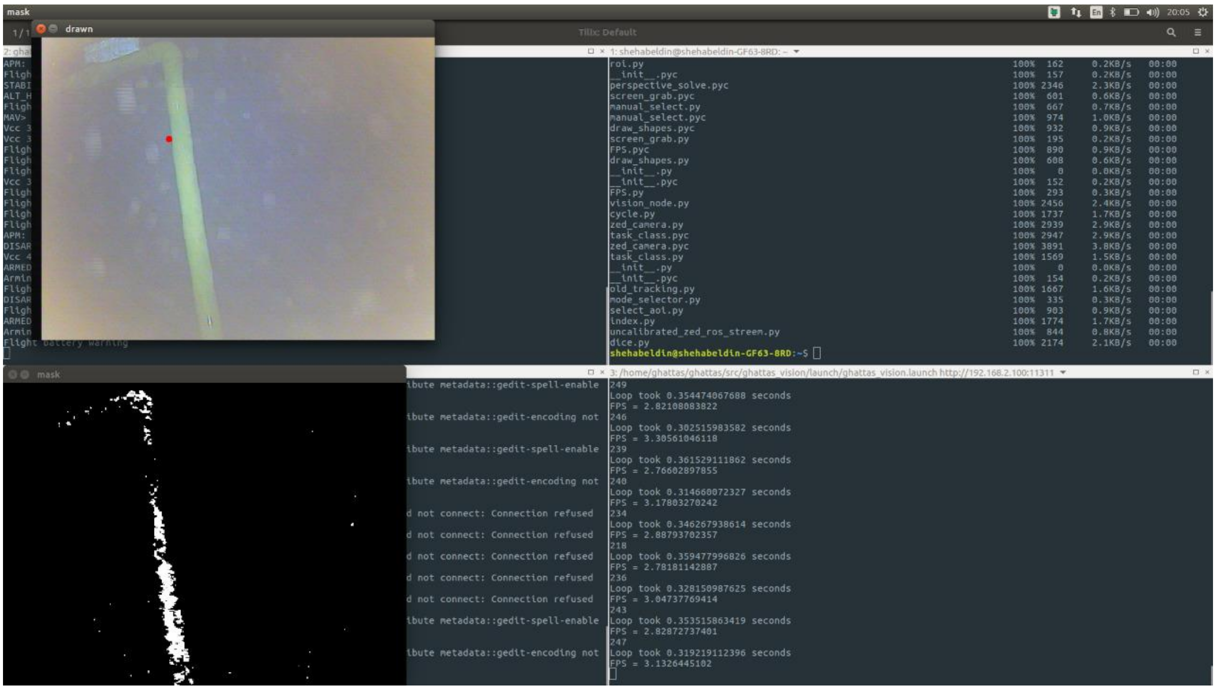


Figure 6-13 Real-time masking for gate detection

6.2. The constraints

Prototype 1 ROV CC01 has the following constraints in its operations, which limit its ability to perform the intended task or the speed at which it preforms them:

a) Limited power from power supply limiting thruster speed
b) Low processing power of on-board PC
c) Poor camera resolution (640x480)

Prototype 2 AUV CC02 will aim to avoid these constraints alongside the addition of extra features and functionalities.

During the manufacturing and assembly of prototype 1 we faced the following limitations:

a) Limited manufacturing facilities
b) High cost of components
c) Difficulty in precuring parts and components

During testing phase of Prototype 1 we faced the following difficulties and challenges:

a) Inconvenient location of testing facility
b) Limited depth of testing pool (2 meters)
c) Lack of resources at testing facilities

Chapter 7 - CONCLUSIONS and FUTURE WORKS

7.1. The conclusions

AUVs have vastly improved underwater exploration in various fields of marine science. They helped raise awareness about environmental issues that are exponentially affecting marine life as our oceans are threatened like never before. Moreover, it is not only reduced the risk that divers face when they dive in dangerous environments or deep depths, but also increased the overall efficiency and effectiveness of complex underwater procedures, such as oil rig maintenance and other search and retrieval operations.

The vehicle's main three subsystems are the mechanical, electrical and control systems, where they work harmoniously to move the vehicle to the desired position, maintain its depth and adjust its stability. The control system gathers data from the vehicle's camera system, it decides the path to be followed, then send a signal to the electrical system. Next, the electrical components amplify the signal and adjust the power to be delivered for each thruster. The mechanical system calculations are made to precisely choose the thrusters' locations, performing the necessary calculations for buoyancy and stability, designing and implementing desired mechanisms and building a rigid and compact chassis.

Most of the Prototype One ROV CC01 design, development and testing parameters have and verified and validated. The design process of Prototype Two, AUV CC02 is currently being finalized and the manufacturing process has begun.

7.2. The future works

The design has so much room for improvement and further development, since it was designed with further development in mind, that is why the vehicle is extremely modular, making it easy to improve one part or functionality without having to sacrifice the entire design and start from scratch all over again, some of these possible improvements that we suggest are as follows.

As we are trying to target our vehicle to be an AUV there is a lot of work that can be done on that aspect from both the software sub-system, and the electric-subsystem, extra sensors can be added such as a Doppler Velocity Logger (DVL) which is a device capable of measuring the speed of the vehicle under water very accurately, which results in a much improved control of the vehicle, another improvement can be made in the cameras by upgrading the mono cameras being used now, to a more expensive stereo camera capable of collecting depth information, which will also significantly improve the vehicles capability to navigate through the mission and improve its ability to identify targets and perform tasks, also it is very important to add the acoustic system to it so that it can control its motion by listening to the source that sends the sound signals and that could be done by the help of Direction of Arrival Estimation (DoAE) and that can be possibly done using various algorithms such as Cramer-Rao Bound (CRB), Cross-Correlation Matrix, Multiple Signal Classification (MUSIC), Estimation of Signal Parameters using Rotational Invariance Techniques (ESPRIT) etc. However, it’s known that the Correlation algorithm is the easiest one so most probably it will be the best choice for our team.

On the software front many optimizations can be achieved using the data that will be collected during testing, also the introduction of some machine learning models trained using the collected data would result in a significant improvement to the accuracy of the control system, another improvement that can be introduced to the software sub-system in the vision system, is the use of simultaneous mapping and localization (SLAM), giving the control system improved special awareness.

Finally, in the mechanical sub-system many improvements can be made by reducing the size of the vehicle, and by building the vehicle using higher quality materials making it more light weight and more robust, also stronger thrusters can be used to improve the speed and maneuverability of the vehicle.

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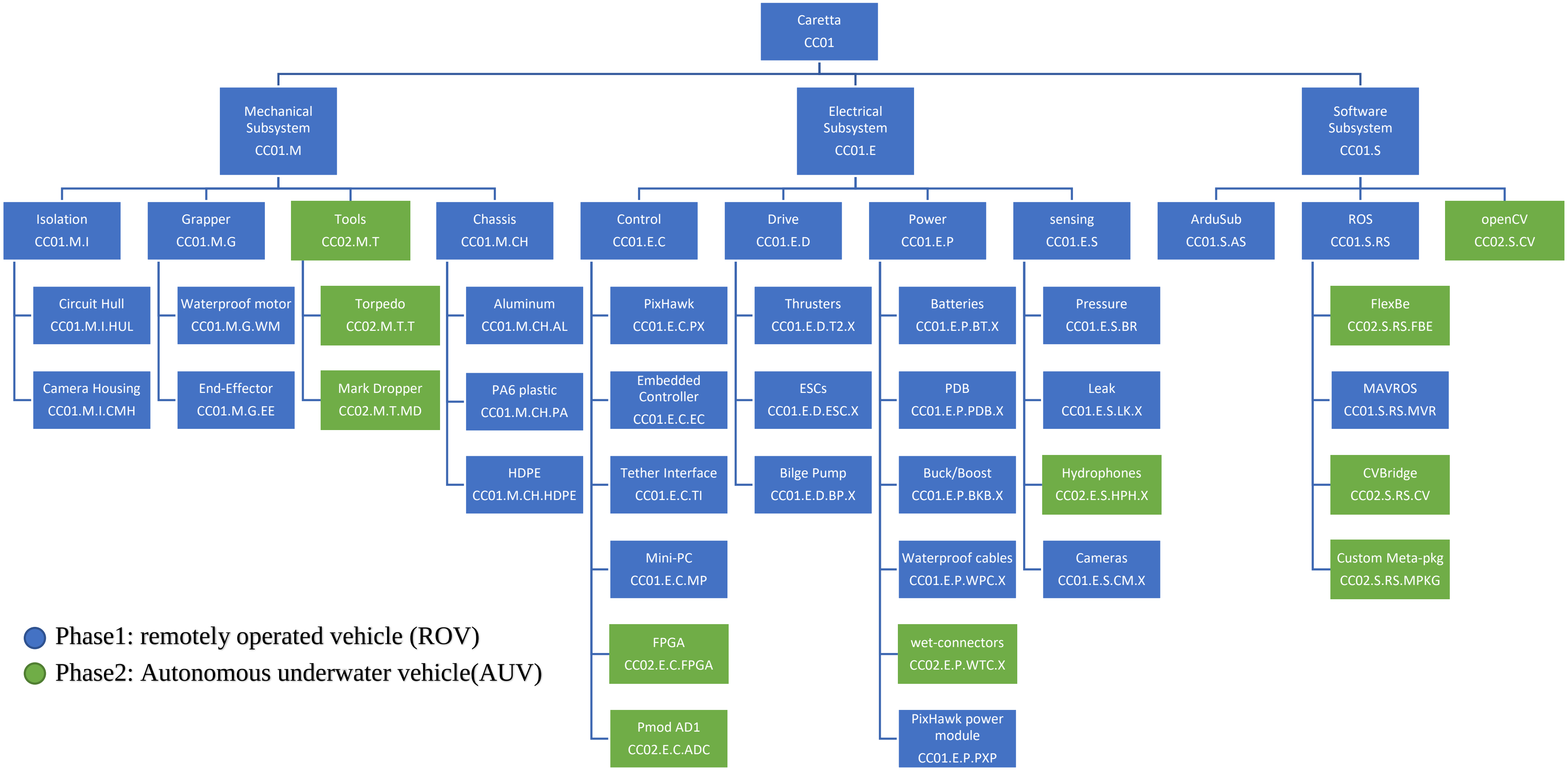
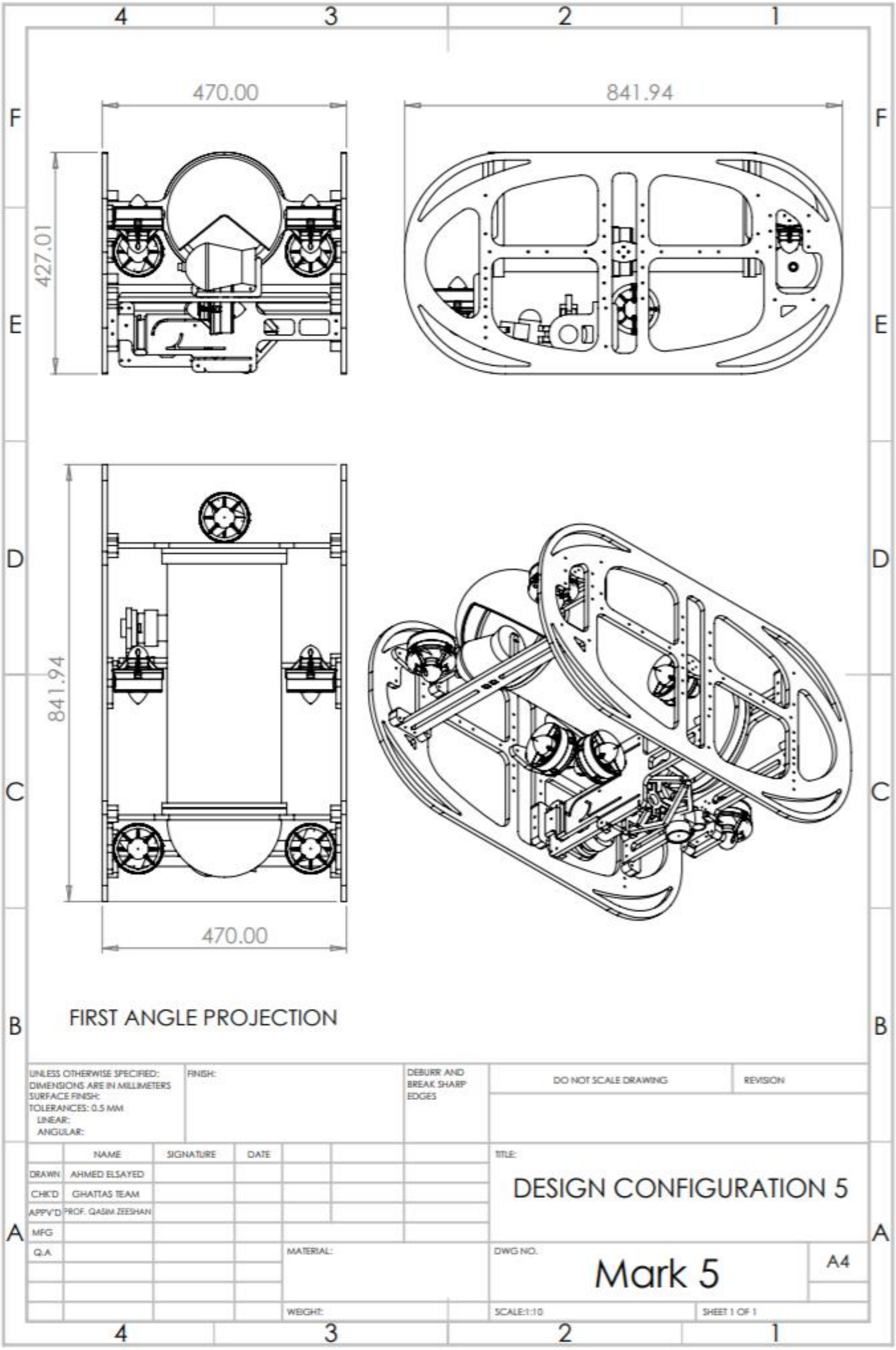
Poster

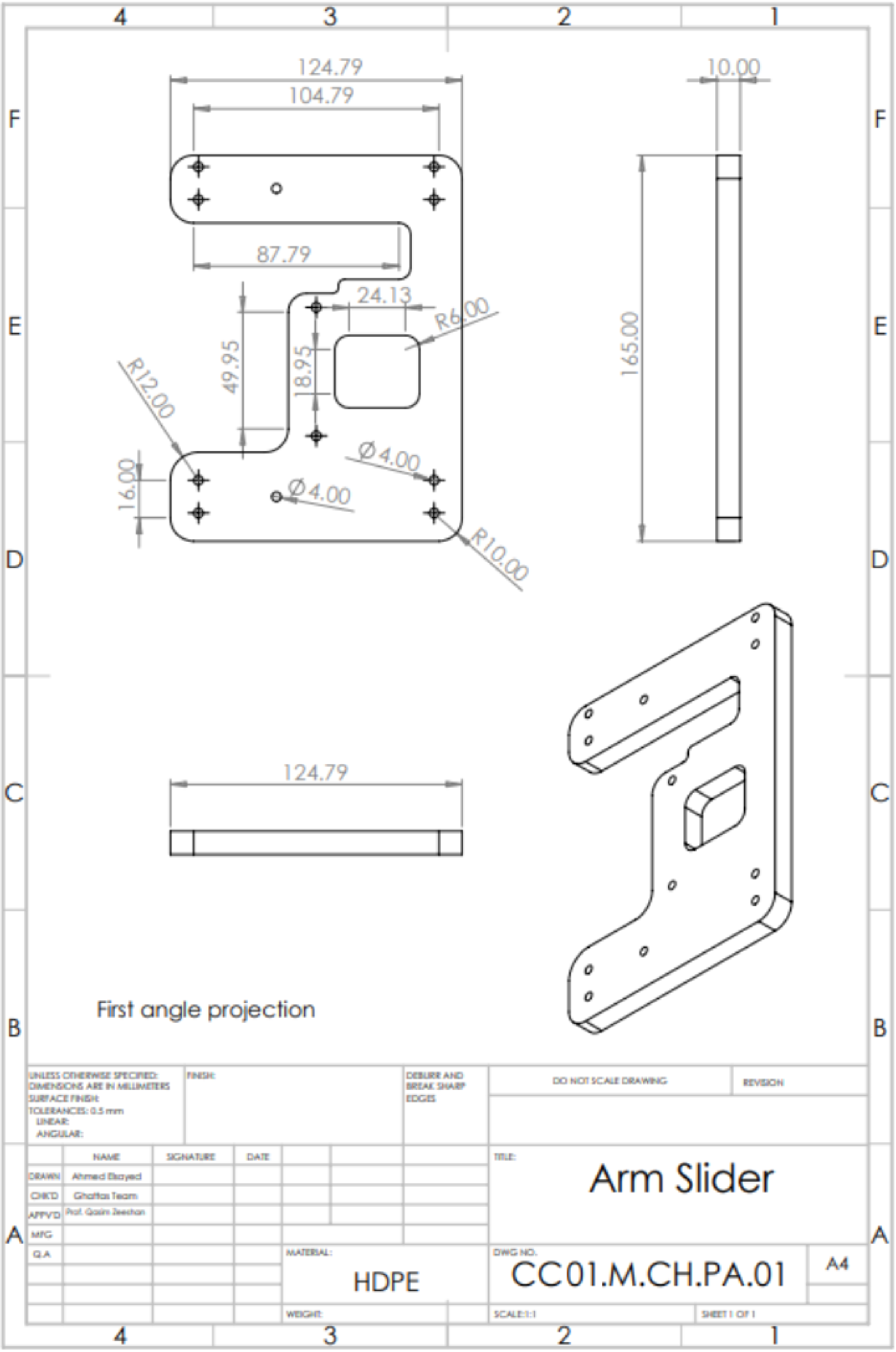
CARETTA CARETTA
SEMI AUTONOMOUS
THRUST FORCE 100N
RATED DEPTH 50m
SMART VISION SYSTEM
MULTIFUNCTION GRIPPER
ONSHORE WEIGHT 14KG
EMU-CARETTA-01
UNMANNED UNDERWATER VEHICLE
THE CARETTA² - UUV
Featuring a compact, modular design, upgradable autonomous capabilities, a custom made gripper, six BlueRobotics T200 thrusters , an HD camera and a 360 camera, caretta is perfect for underwater inspection and scientific research operations. Our specially designed, easy to use software system enables seamless and precise control of the vehicle, allowing it to perform the desired missions in the most efficient way.
360°camera
GRIPPER

APPENDIX A: System Breakdown Structure (BDS)



APPENDIX B: Engineering Drawings





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Ø4.00
R10.00
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First angle projection
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TOLERANCES: 0.5 mm
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN Ahmed Elsayed
CHK'D Ghattas Team
APPV'D Prof. Qasim Zeeshan
MFG
Q.A
TITLE:
Arm Slider
MATERIAL:
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DWG NO.
CC01.M.CH.PA.01
A4
WEIGHT:
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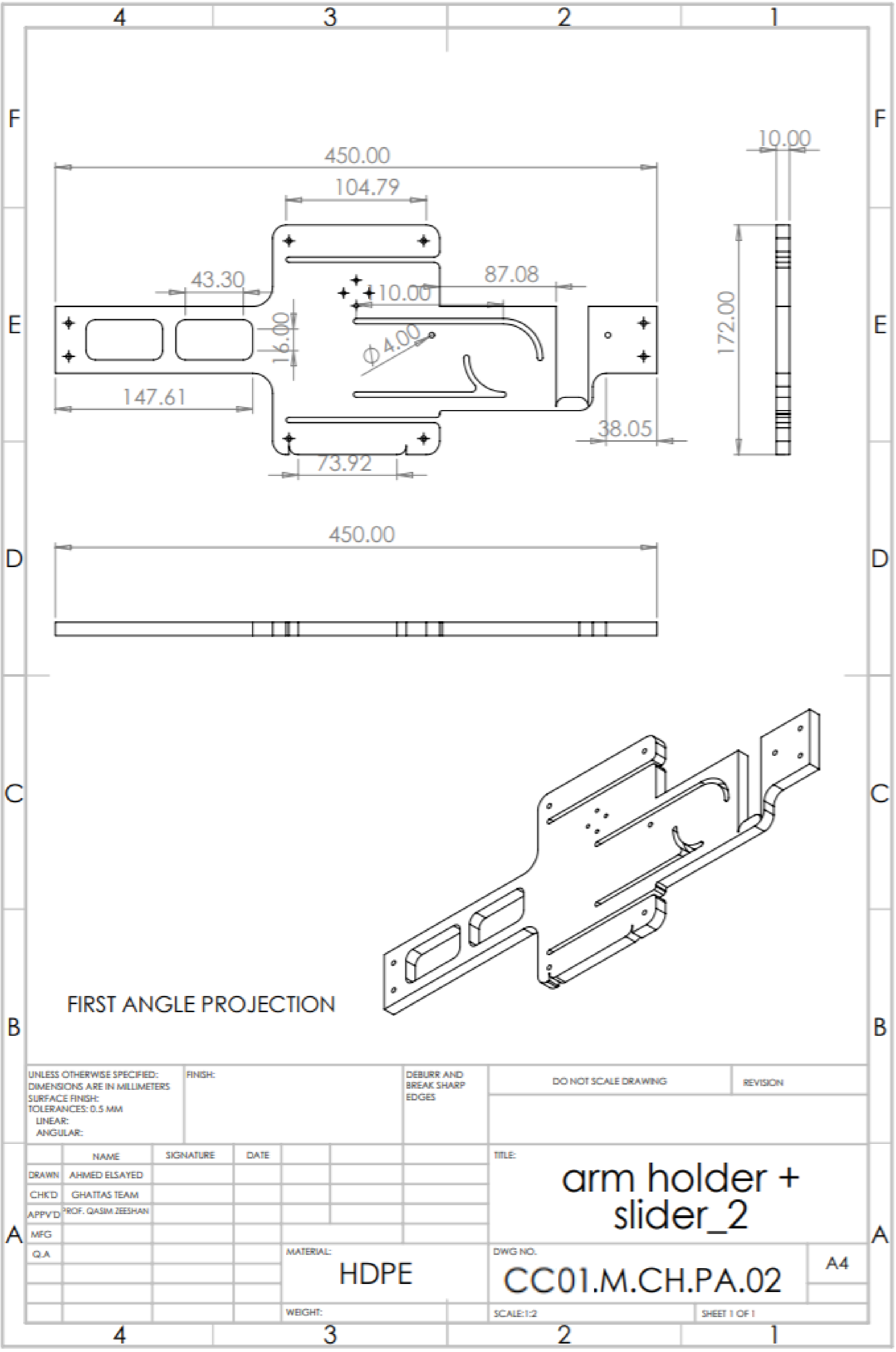
SHEET 1 OF 1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TOLERANCES: 0.5 MM
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN AHMED ELSAYED
CHK'D GHATTAS TEAM
APPV'D PROF. QASIM ZEESHAN
MFG
Q.A
TITLE:
arm holder + slider_2
MATERIAL:
HDPE
DWG NO.
CC01.M.CH.PA.02
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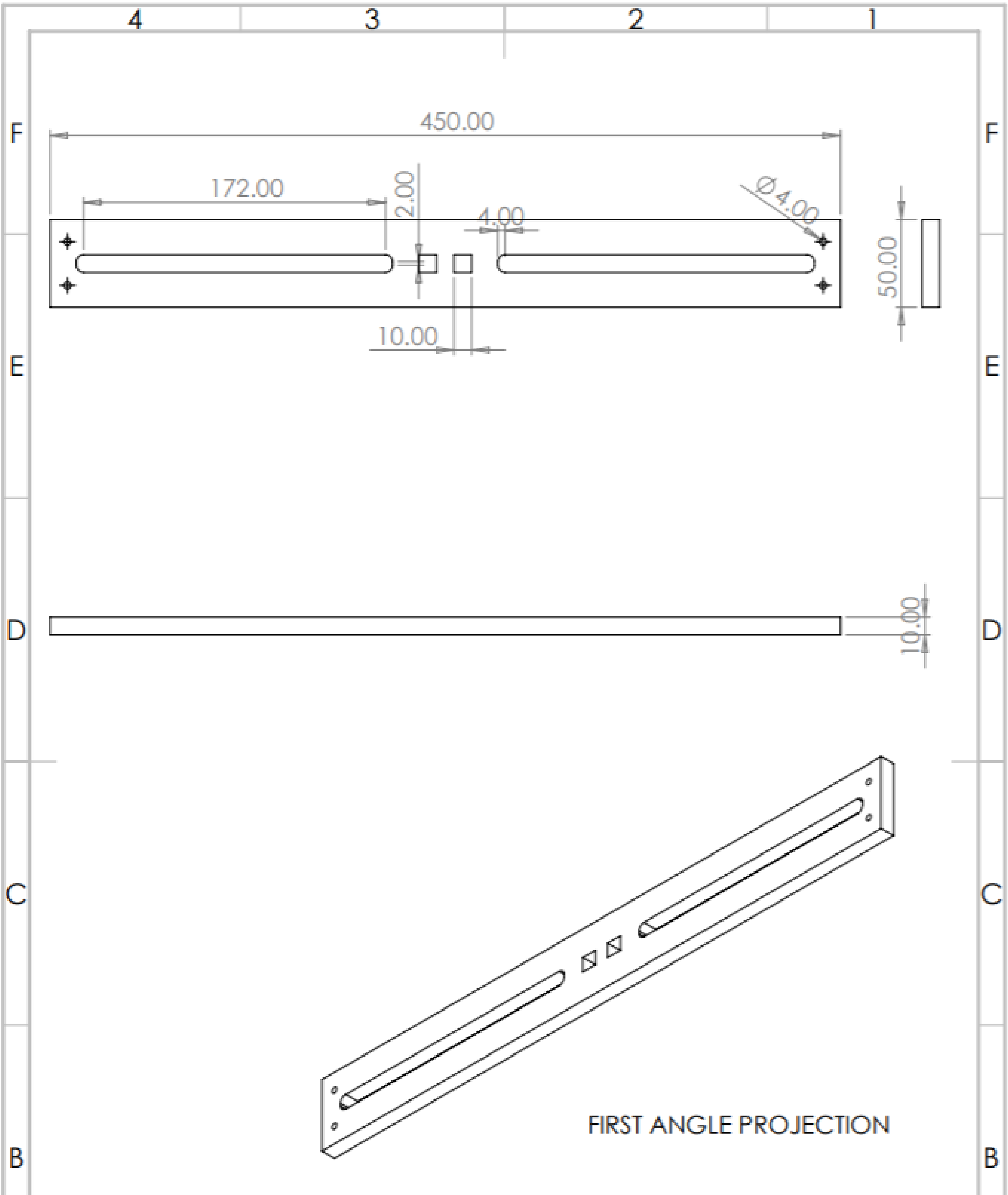
WEIGHT:
SCALE:1:2
SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:
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SURFACE FINISH:
TOLERANCES: 0.5 MM
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	AHMED ELSAYED		
CHK'D	GHATTAS TEAM		
APPV'D	PROF. QASIM ZEESHAN		
MFG			
Q.A			

TITLE: fixed cam supp_5

MATERIAL: HDPE

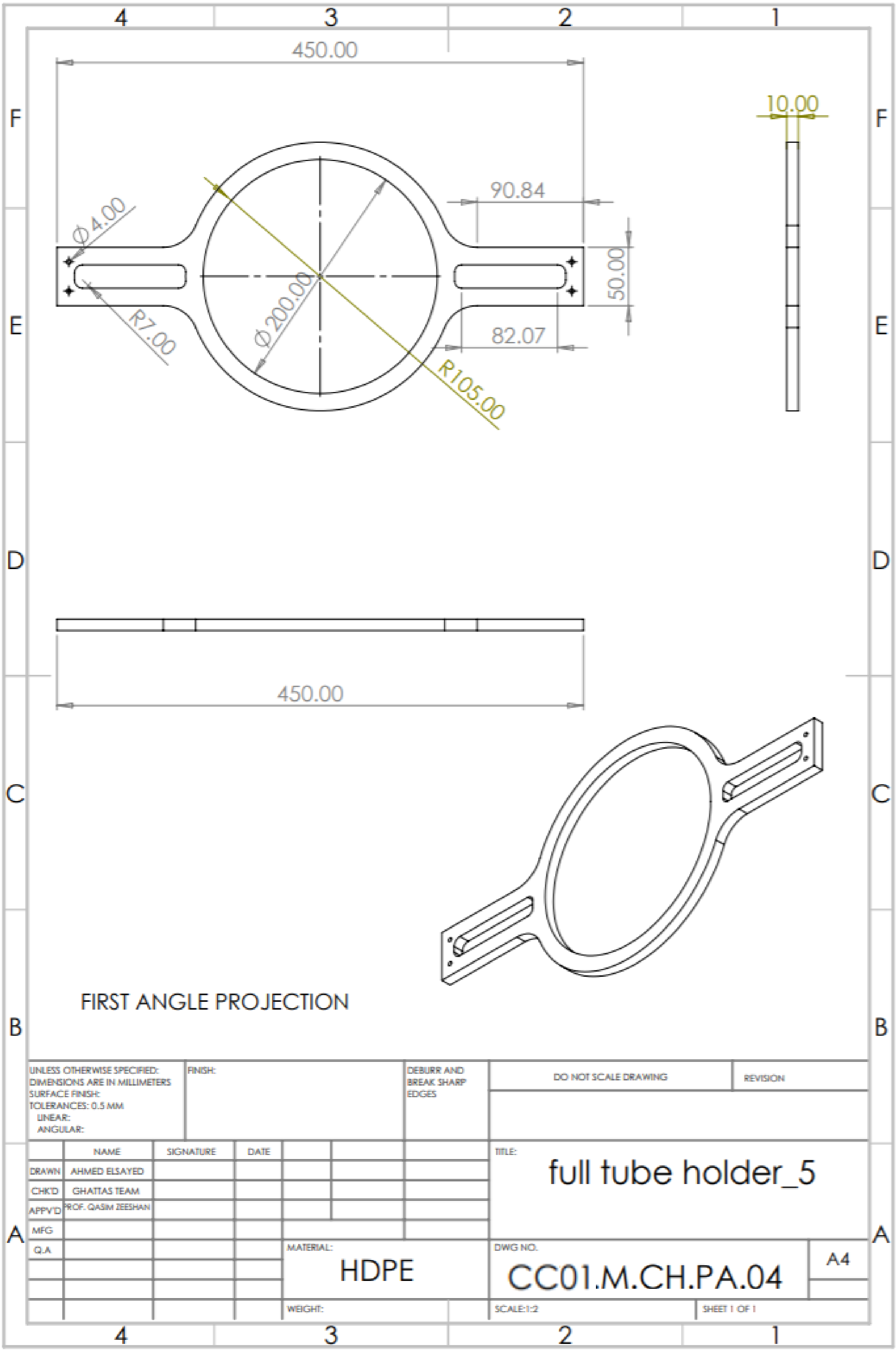
DWG NO. CC01.M.CH.PA.03

A4

WEIGHT:

SCALE:1:2

SHEET 1 OF 1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Ø200.00
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R105.00
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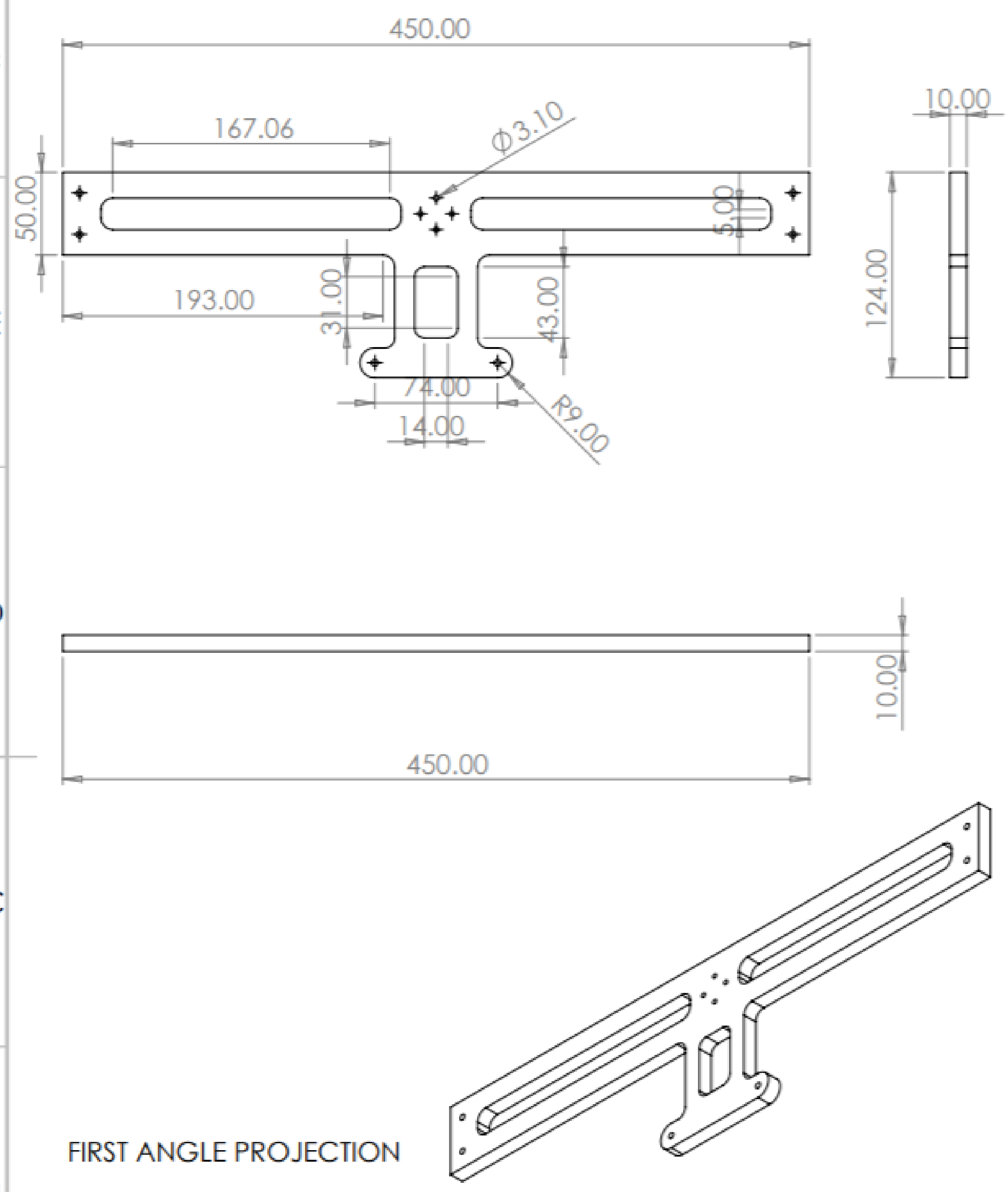
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES: 0.5 MM
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN AHMED ELSAYED
CHK'D GHATTAS TEAM
APPV'D PROF. QASIM ZEESHAN
MFG
Q.A
TITLE:
full tube holder_5
MATERIAL:
HDPE
DWG NO.
CC01.M.CH.PA.04
A4
WEIGHT:
SCALE:1:2
SHEET 1 OF 1



FIRST ANGLE PROJECTION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES: 0.5 MM
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	AHMED ELSAYED		
CHK'D	GHATTAS TEAM		
APPV'D	PROF. QASIM ZEESHAN		
MFG			
Q.A			

TITLE: mot supp 4_2

MATERIAL: HDPE

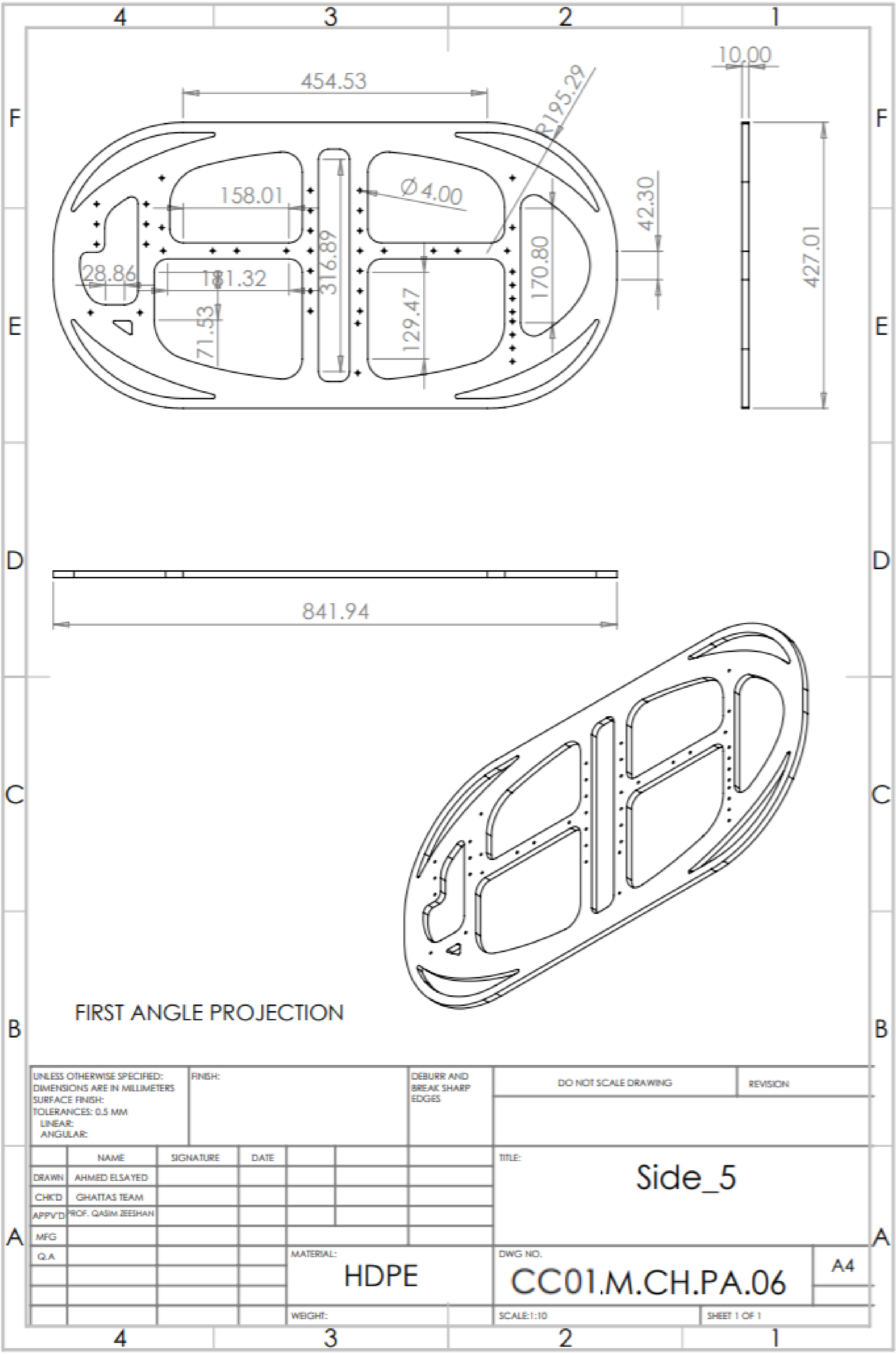
DWG NO. CC01.M.CH.PA.05

A4

WEIGHT:

SCALE:1:2

SHEET 1 OF 1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FIRST ANGLE PROJECTION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES: 0.5 MM
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN AHMED ELSAYED
CHK'D GHATTAS TEAM
APPV'D PROF. QASIM ZEESHAN
MFG
Q.A
TITLE:
Side_5
MATERIAL:
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CC01.M.CH.PA.06
A4
WEIGHT:
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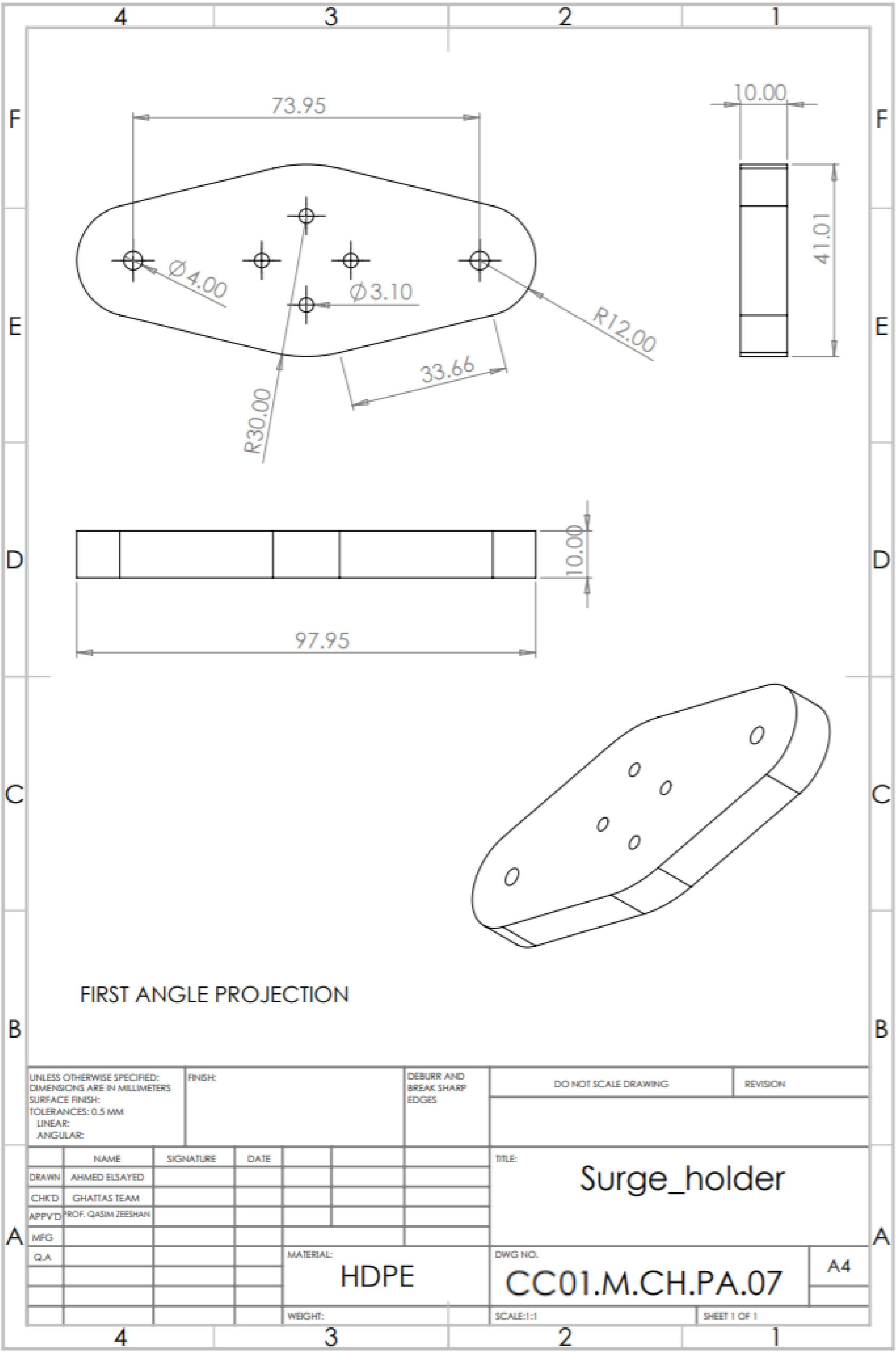
SHEET 1 OF 1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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES: 0.5 MM
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN AHMED ELSAYED
CHK'D GHAITAS TEAM
APPV'D PROF. QASIM ZEESHAN
MFG
Q.A
TITLE:
Surge_holder
MATERIAL:
HDPE
DWG NO.
CC01.M.CH.PA.07
A4
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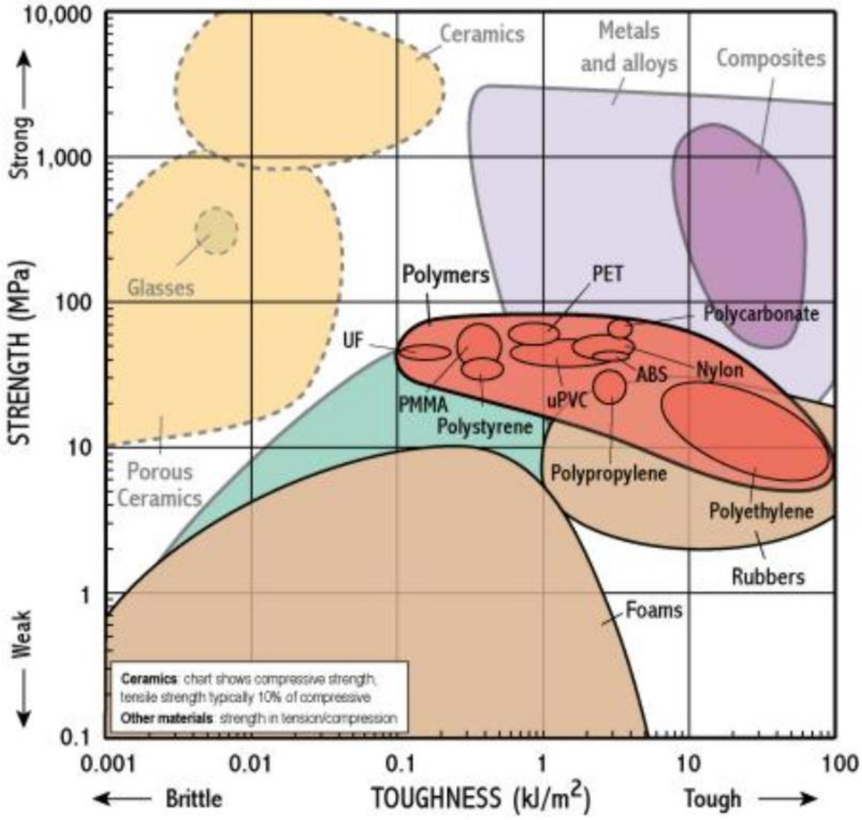
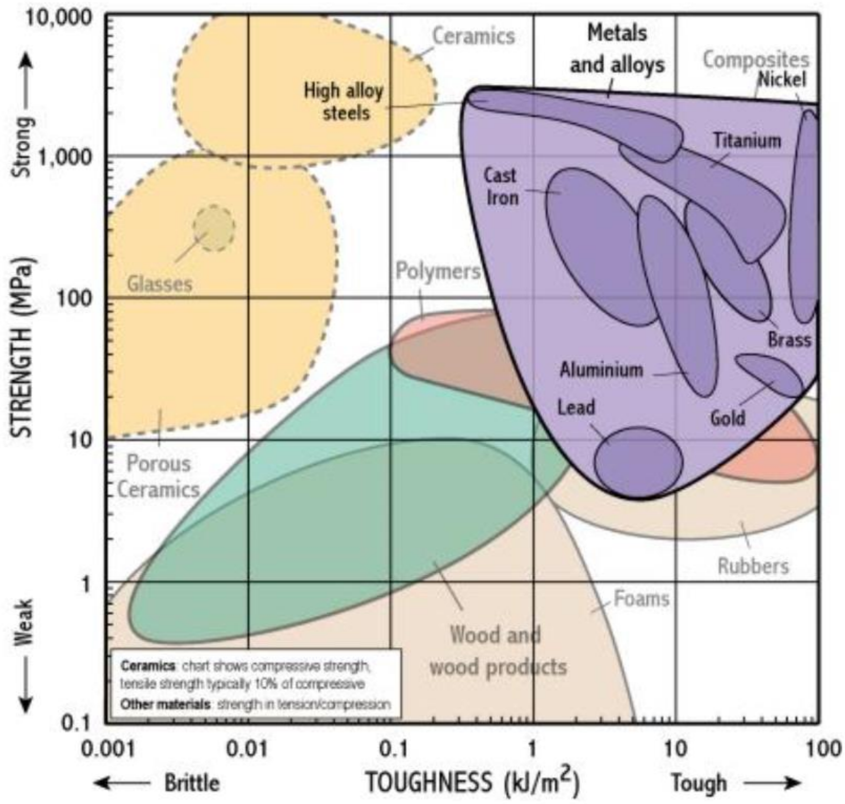
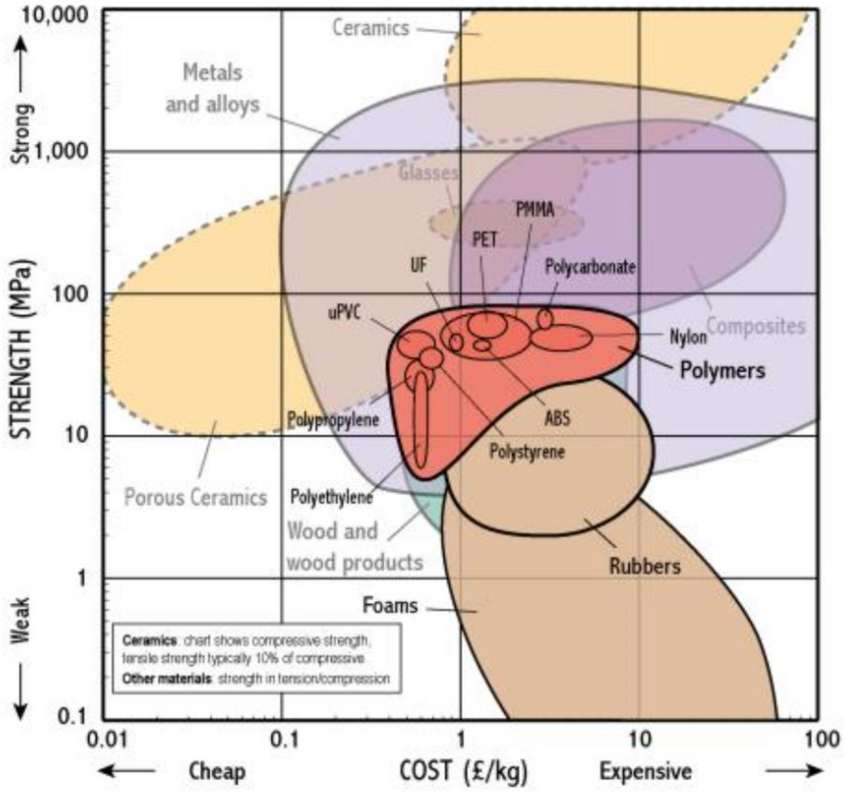
SHEET 1 OF 1

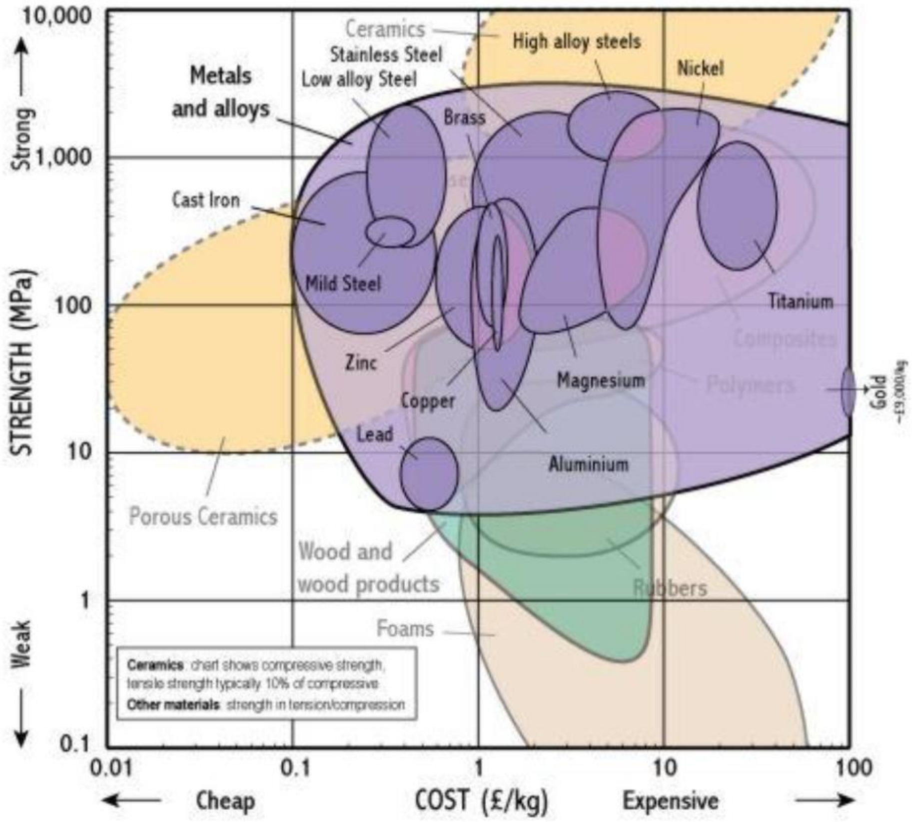
APPENDIX C: Logbook

APPENDIX D: Ashby Charts (material selection)



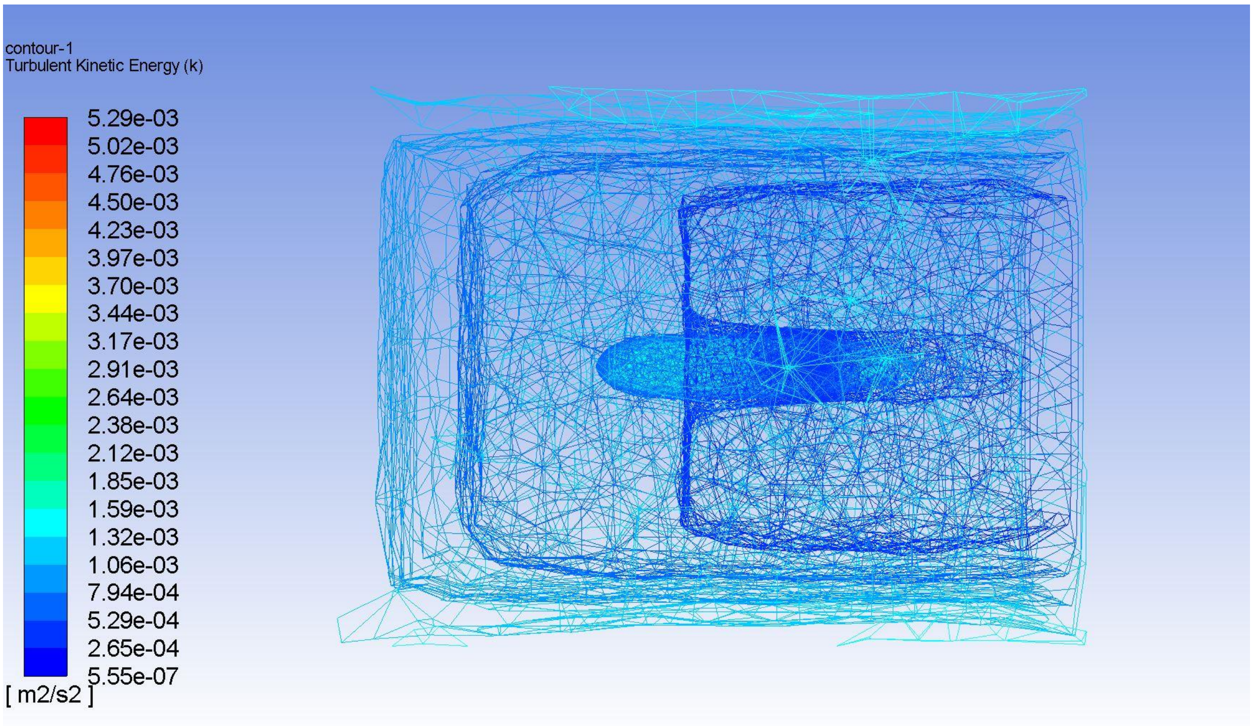



STRENGTH (MPa)
COST (£/kg)
Strong
Weak
Cheap
Expensive
Ceramics
Metals and alloys
Glasses
PMMA
PET
UF
Polycarbonate
uPVC
Nylon
Composites
Polymers
Polypropylene
ABS
Polystyrene
Porous Ceramics
Polyethylene
Wood and wood products
Rubbers
Foams
Ceramics: chart shows compressive strength, tensile strength typically 10% of compressive
Other materials: strength in tension/compression


STRENGTH (MPa)
COST (£/kg)
Strong
Weak
Cheap
Expensive
Ceramics
High alloy steels
Stainless Steel
Metals and alloys
Low alloy Steel
Nickel
Brass
Cast Iron
Mild Steel
Titanium
Zinc
Composites
Magnesium
Polymers
Copper
Gold ~£9,000/kg
Lead
Aluminium
Porous Ceramics
Wood and wood products
Rubbers
Foams
Ceramics: chart shows compressive strength, tensile strength typically 10% of compressive
Other materials: strength in tension/compression

APPENDIX E: Computational Fluid Dynamics (CFD) Analysis of the Torpedo

Here is the calculation of the drag coefficient and drag force obtained from the simulation



turbulence simulation

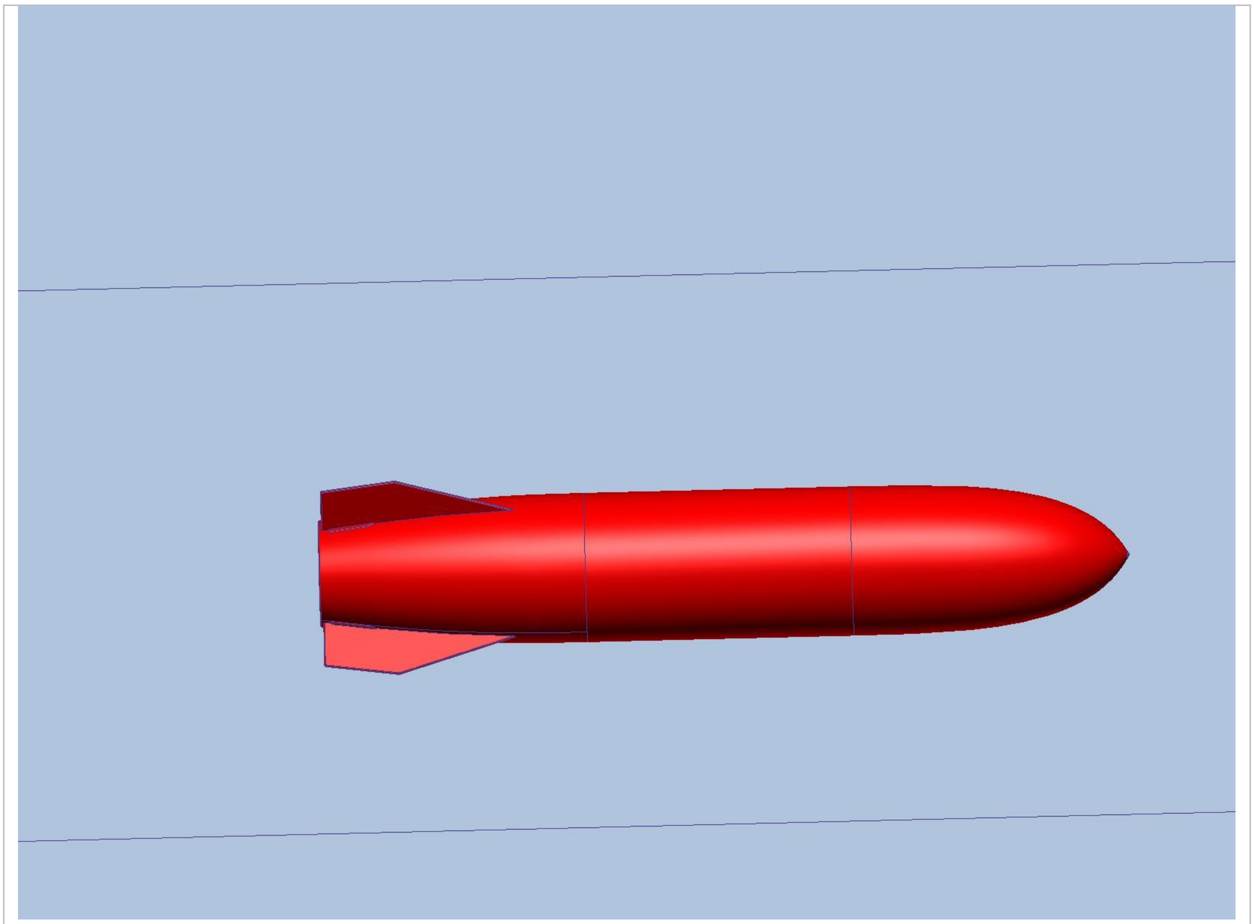
And here is the report which obtained from simulation program used

Design 1

Length units	Meter
Coordinate system	Cartesian 3D

Scenario 1

Materials



Name	ASSIGNED TO	PROPERTIES	
ABS (Molded)	torpedo-missile-2	X-Direction Y-Direction Z-Direction Density Specific heat Emissivity Transmissivity Electrical resistivity Wall roughness	0.153 W/m-K Same as X-dir. Same as X-dir. 1.05 g/cm3 2.05 J/g-K 0.469 0.0 1.65e+15 ohm-cm 0.0 meter
Sea Water (Liquid phase)	CFD Created Volume	Density Viscosity Conductivity Specific heat Compressibility Emissivity Wall roughness Phase	1021.2 kg/m3 0.0011404 Pa-s 0.59 W/m-K 5608.2 J/kg-K 2431320000.0 Pa 1.0 0.0 meter Linked Vapor

boundary conditions

Type	ASSIGNED TO
Pressure (0 Pa Gage)	Surface:99
Velocity Normal (0.5 m/s)	Surface:104

Initial Conditions

Type	ASSIGNED TO

mesh

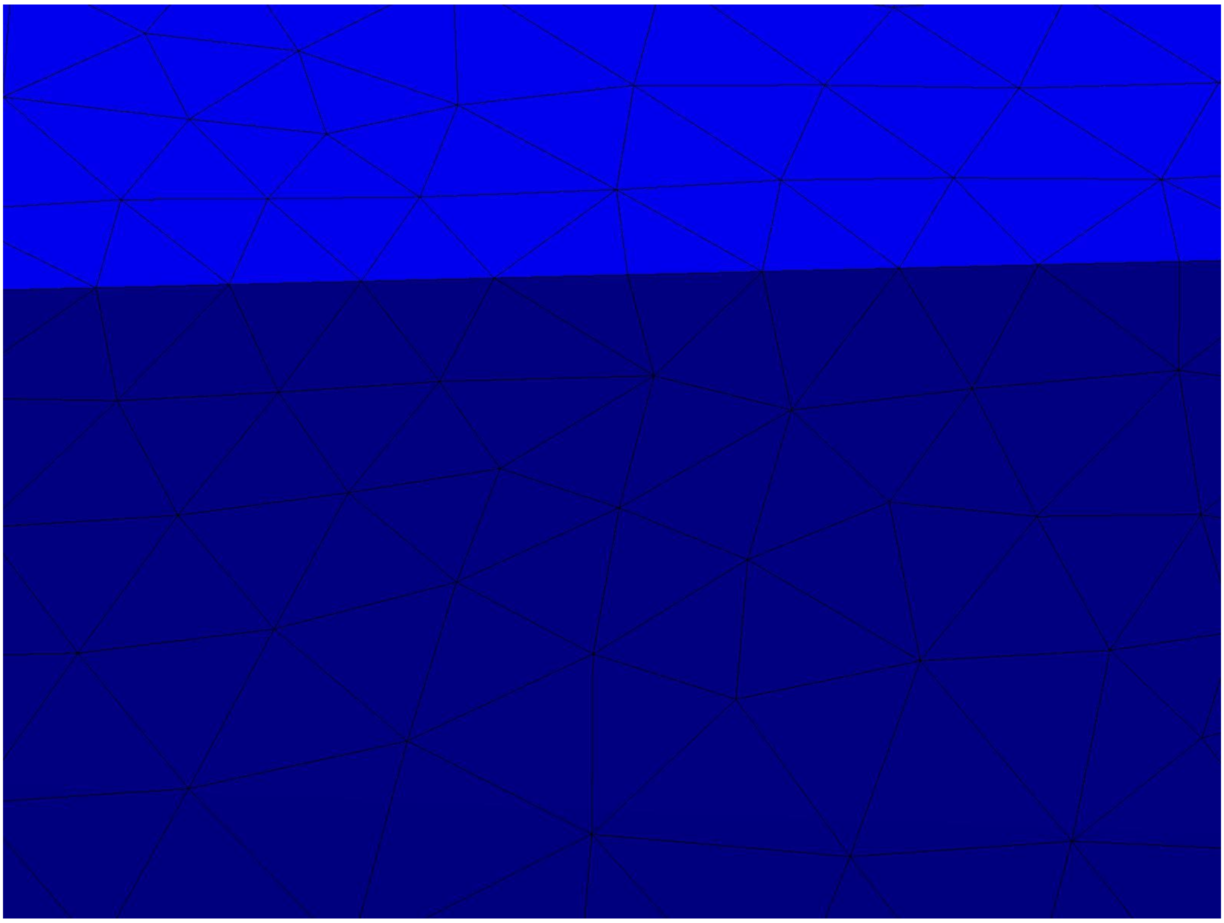
Automatic Meshing Settings

Surface refinement	0
Gap refinement	0
Resolution factor	1.0
Edge growth rate	1.08
Minimum points on edge	2
Points on longest edge	10
Surface limiting aspect ratio	20

Mesh Enhancement Settings

Mesh enhancement	1
Enhancement blending	0
Number of layers	3
Layer factor	0.45
Layer gradation	1.05

Meshed Model



Number of Nodes	89438
Number of Elements	388486

Physics

Flow	On
Compressibility	Incompressible
Heat Transfer	Off
Auto Forced Convection	Off
Gravity Components	0.0, 0.0, 0.0
Radiation	Off
Scalar	No scalar
Turbulence	On

Solver Settings

Solution mode	Steady State
Solver computer	My Computer
Intelligent solution control	On
Advection scheme	ADV 5
Turbulence model	k-epsilon

Convergence

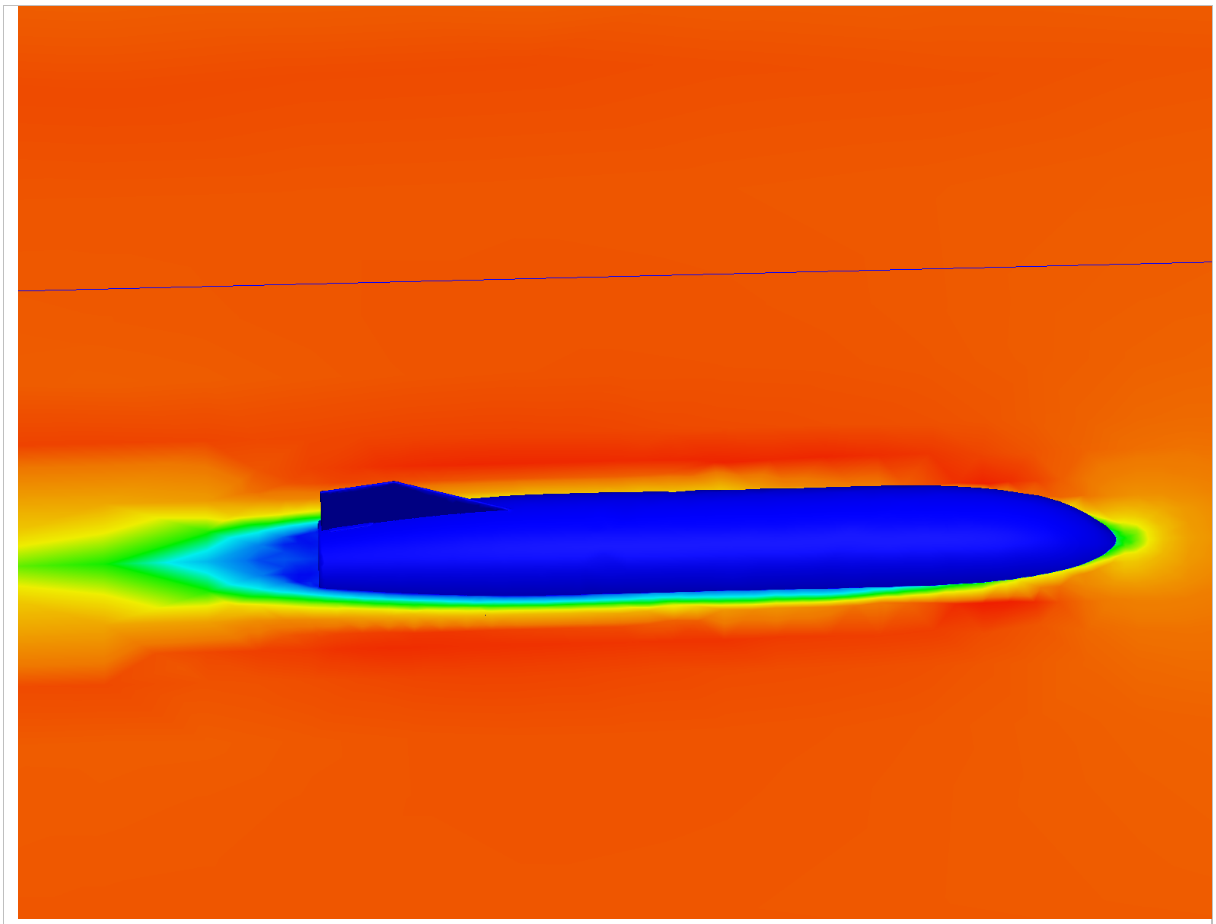
Iterations run	400
Solve time	1679 seconds
Solver version	19.1.20180819

Energy Balance

Mass Balance

	In	Out
Mass flow	45.4179 kg/s	-45.4105 kg/s
Volume flow	0.0444751 m^3/s	-0.0444678 m^3/s

Results



Inlets and Outlets

inlet 1	inlet bulk pressure	11.8514 N/m^2
	inlet bulk temperature	0.0 C
	inlet mesh number	3.40579e-08
	mass flow in	45.4179 kg/s
	minimum x, y, z of	0.0
	node near minimum	10611.0
	Reynolds number	132754.0
	surface id	104.0
	total mass flow in	45.4179 kg/s
	total vol. flow in	0.0444751 m^3/s
	volume flow in	0.0444751 m^3/s
outlet 1	mass flow out	-45.4105 kg/s
	minimum x, y, z of	0.0
	node near minimum	8989.0
	outlet bulk pressure	-0.0 N/m^2
	outlet bulk	-0.0 C
	outlet Mesh number	3.20287e-08
	Reynold’s number	132733.0

	surface id	99.0
	total mass flow out	-45.4105 kg/s
	total vol. flow out	-0.0444678 m^3/s
	volume flow out	-0.0444678 m^3/s

Field Variable Results

Variable	Max	Min
cond	0.59 W/m-K	0.153 W/m-K
dens	1050.0 kg/m^3	1021.2 kg/m^3
econd	189955.0 W/m-K	0.0 W/m-K
emiss	1.0	0.0
evisc	118.595 kg/m-s	0.0 kg/m-s
gent	189517.0 1/s	0.00948995 1/s
press	157.068 N/m^2	-39.9217 N/m^2
ptotl	173.585 N/m^2	-39.9217 N/m^2
scal1	0.0	0.0
seebeck	0.0 V/K	0.0 V/K
shgc	0.0	0.0
spech	5608.2 J/kg-K	2050.0 J/kg-K
temp	0.0 C	0.0 C
transmiss	0.0	0.0
turbd	480.851 m^2/s^3	2.58827e-07 m^2/s^3
turbk	0.088197 m^2/s^2	3.16102e-07 m^2/s^2
ufactor	0.0	0.0
visc	0.0011404 kg/m-s	0.0 kg/m-s
vx vel	0.193085 m/s	-0.194979 m/s

vy vel	0.187629 m/s	-0.191142 m/s
vz vel	0.053449 m/s	-0.559331 m/s
wrough	0.0 m	0.0 m

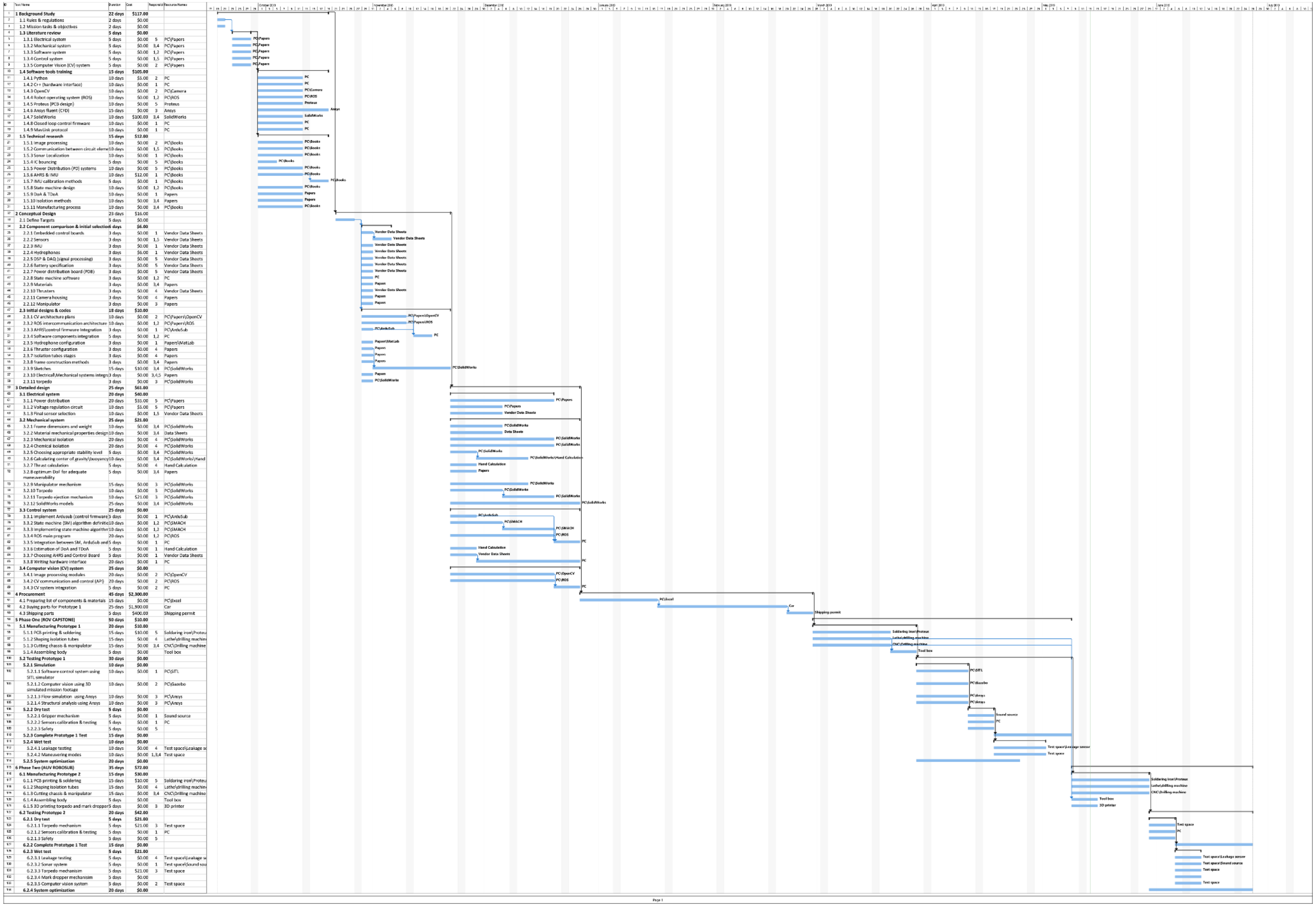
Component Thermal Summary

Part	Minimum Temperature	Maximum Temperature	Volume Averaged Temperature
torpedo-missile-2	0	0	0
CFDCreatedVolume	0	0	0

Fluid Forces on Walls

pressx	-0.0033594 Newtons
pressy	-0.00063145 Newtons
pressz	-0.010535 Newtons
shearx	7.6466e-05 Newtons
sheary	-3.7367e-05 Newtons
shearz	-0.81154 Newtons

APPENDIX F: Project Timeline



APPENDIX G: DATA SHEETS

Mechanical Subsystem:

Al 6063 6063:

Atlas Steels

Aluminium Alloy Data Sheet

6063

Specified Properties

These properties are specified for extruded product (bar, rod, solid and hollow shapes) in AS/NZS 1866:1997. Similar but not necessarily identical properties are specified in AA and ASTM and other specifications and for other products.

Composition Specification (%) (single values are maxima except as noted)

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others	
									Each	Total
6063	0.20-0.6	0.35	0.10	0.10	0.45-0.9	0.10	0.10	0.10	0.05	0.15

Mechanical Property Specification (single values are minima except as noted)

Alloy & Temper	Diameter or Thickness (mm)	Tensile Strength (MPa)	Yield Strength 0.2% Proof (MPa) min	Elongation (%) (GL = 50mm or 5.65√A) min
6063-O	All	130 max	-	16
6063-T1	Up to 12.0	115 min	60	12
	12.0 – 25.00	110 min	55	10
6063-T5	Up to 12.0	150 min	110	8
	12.0 – 25.00	145 min	105	6
6063-T6	Up to 25.00	205 min	170	8
Other tempers such as T42, T52 and T62 are also possible in 6063 – refer to standards for details.				

Physical Properties (typical values)

Alloy	Density (kg/m³)	Elastic Modulus (GPa)	Mean Coefficient of Thermal Expansion 20-100°C (µm/m/°C)	Thermal Conductivity at 25°C (W/m.K)	Electrical Conductivity MS/m at 20°C		Electrical Resistivity (nΩ.m)
					Equal Volume	Equal Mass	
6063	2700	69	23.4	209	32	105	31

Grade Specification Comparison

Alloy	UNS No	ISO	BS	DIN	
				No	Name
6063	A96063	AlMgSi	H19	3.3206	AlMgSi0.5
These comparisons are approximate only. The list is intended as a comparison of functionally similar materials **not** as a schedule of contractual equivalents. If exact equivalents are needed original specifications must be consulted.					

Possible Alternative Alloys

Alloy	Why it might be chosen instead of 6063
5052	Similar or higher strength required in a flat rolled sheet or plate form

References

- AS/NZS 1866:1997 Aluminium And Aluminium Alloys – Extruded Rod, Bar, Solid And Hollow Shapes.
- Aluminum Association – Aluminum Standards and Data – 2009 Metric SI.
- WTIA Technical Note 2 – Successful Welding of Aluminium.

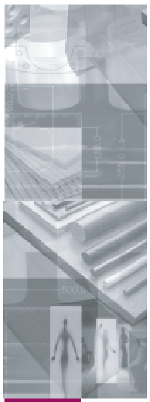
Limitation of Liability

The information contained in this datasheet is not an exhaustive statement of all relevant information. It is a general guide for customers to the products and services available from Atlas Steels and no representation is made or warranty given in relation to this document or the products or processes it describes.

Polypropylene Mechanical Properties:

Tensile Strength	0.95 - 1.30 N/mm^2
Notched Impact Strength	3.0 - 30.0 Kj/m^2
Thermal Coefficient of expansion	100 - 150 x 10-6
Max Cont Use Temp	80 °C
Density	0.905 g/cm3

PVC (POLYVINYL CHLORIDE):



PRODUCT DATA SHEET

Bay Plastics Ltd

plastic stockholders and plastic fabrication

for all your plastic requirements

PVC (POLYVINYL CHLORIDE)

PVC is polyvinylchloride and comes in many different forms. In general, PVC is light, water resistant, offers a long life cycle and does not require much maintenance. These excellent qualities makes PVC one of the most commonly used plastics today. General properties include fast fusion and good property flow with high heat stability. Excellent transparency, good surface of finished products and easy colouring.

Technical Specification

	Test method	Units	U-PVC	C-PVC
Physical Properties				
Specific gravity (p)	DIN 53479	g/cm³	1.36	1.55
Water absorption	DIN 53495	%	0.2	0.2
Chemical Resistance	DIN 53476	-	DIN 8061	DIN 8061
Max. permissible service temperature (no stronger mech. stress involved)				
upper temperature limit -		°C	60	85
lower temperature limit -		°C	-5	-5
Mechanical Properties				
Tensile stress at yield	DIN 53455	MPa	55	57
Elongation at yield	DIN 53455	%	3	3
Tensile strength at break	DIN 53455	MPa	30	80
Elongation at break	DIN 53455	%	33	15
Impact strength	DIN 53453	kJ/m²	o.B.	o.B.
Notch impact strength	DIN 53453	kJ/m²	3	8
Ball indentation hardn. / Rockwell	DIN 53456	MPa	120	150
Modulus of elasticity	DIN 53457	MPa	3000	3000
Thermal Properties				
Vicat softening temp. VST/B/50 VST/A/50 °C	DIN 53460	°C	75 2)	105
Heat deflection temperature HDT/B HDT/A °C	DIN 53461	°C	72 3)	102
Coef. of linear therm. expansion	DIN 53752	$k^{-1} \times 10^{-4}$	0.8	0.6
Thermal conductivity at 20 °C	DIN 52612	W / (m*k)	0.14	0.14
Electrical Properties				
Volume resistivity	DIN 53482	Ω x cm	$>10^{15}$	$>10^{15}$
Surface resistivity	DIN 53482	Ω	$\geq 10^{13}$	$\geq 10^{13}$
Dielectric constant at 1 MHZ	DIN 53483		3	3
Dielectric loss factor at 1 MHZ	DIN 53483		0.01	0.01
Dielectric strength	DIN 53481	kV/mm	20-40	20-40
Tracking resistance	DIN 53480		KB 600	KB 600

The data are typical values and are not intended to represent specifications. Their aim is to guide the user towards a material choice. All statements , technical information and recommendation in this product data sheet are presented in good faith, based upon test believed to be reliable and practical experience. However, Bay Plastics Ltd cannot guarantee the accuracy or completeness of this information, and, it is the buyer responsibility to determine the suitability of products in any given application. Therefore no liability whatsoever shall attach to Bay Plastics Ltd for any infridgement of the rights owned ot controlled by a third party in intellectual, industrial or other property by reason of application, processing or use of the aforementioned information or products by the buyer.

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ABS:

Innofil3D make anything!

Preparation date: 09-06-2016 Version No.: 2.0

Technical Data Sheet

ABS by Innofil3D BV

Filament suitable for all commercially available leading brands 3D FDM/FFF printers

IDENTIFICATION OF THE MATERIAL	
Trade name	Innofil3D ABS
Chemical name	Acrylonitrile Butadiene Styrene
Chemical family	Thermoplastic Copolymers
Use	3D-Printing
Origin	Innofil3D BV

GUIDELINE FOR PRINT SETTINGS	
Nozzle temperature	240 ± 10 °C
Bed temperature	80 – 100 °C
Bed modification	Tape
Active cooling fan	No/Yes (up to 25%)
Layer height	0.08 – 0.2 mm
Shell thickness	0.4 – 0.8 mm
Print speed	40 – 80 mm/s

Settings are based on a 0.4 mm nozzle

MATERIAL PROPERTIES		Test Method
Melt temperature	Not applicable	ASTM D3418
Glass transition temperature	~ 105 °C	ASTM D3418
Melt Flow Rate[1]	43.1 g/10min	ISO 1133
Melt Volume Rate[1]	45.9 cm3/10min	ISO 1133
Density	1.04 g/cm3	ASTM D1505
Odor	Little odor	/
Solubility	Insoluble in water	/

[1]Test conditions: T = 210 °C; m = 2.16 kg

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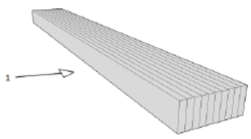
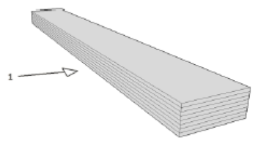
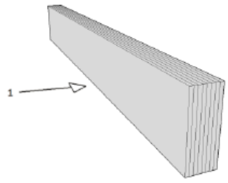
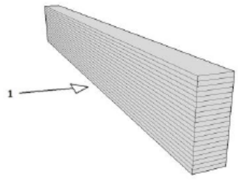
MECHANICAL PROPERTIES | TENSILE TEST — Test Method ISO 527

All test specimens were printed using an Ultimaker 2+ under the following conditions: Printing temperature: 210 °C Heated bed temperature: 60 °C Print speed: 40 mm/s Number of shells: 2 Infill under 45°	 Printed vertical (Z-axis)		 Printed horizontal (X,Y-axis)	
Infill	50%	100%	50%	100%
Tensile strength (MPa)	4.4 ± 0.6	6.5 ± 1.8	17.0 ± 0.8	29.3 ± 0.8
Force at break (MPa)	2.7 ± 1.8	7.8 ± 1.3	13.6 ± 0.8	26.4 ± 1.8
Elongation at max force (%)	0.5 ± 0.1	0.7 ± 0.1	2.3 ± 0.1	2.4 ± 0.1
Elongation at break (%)	0.5 ± 0.2	0.7 ± 0.1	4.8 ± 0.9	3.7 ± 0.9
Relative tensile strength (MPa/g)	0.7 ± 0.1	0.8 ± 0.2	2.5 ± 0.1	3.0 ± 0.1
Emodulus (MPa)	1031 ± 53	1358 ± 139	1072 ± 38	2030 ± 45

MECHANICAL PROPERTIES | IMPACT TEST — Test Method ISO 179

All test specimens were printed using an Ultimaker 2+ under the following conditions: Printing temperature: 210 °C Heated bed temperature: 60 °C Print speed: 40 mm/s Number of shells: 2 Infill under 45° 1→: impact direction	 Charpy (en)	 Charpy (ep)
Infill	100%	100%
Impact strength (kJ/m^2)	39.3 ± 3.3	35.4 ± 3.4
Impact energy (mJ)	1500.0 ± 134.4	1371.6 ± 125.9

MECHANICAL PROPERTIES | FLEXURAL TEST		Test Method ISO 178
All test specimens were printed using an Ultimaker 2+ under the following conditions: printing temperature: 210 °C heated bed temperature: 60 °C print speed: 40 mm/s number of shells: 2 Infill under 45° 1→: bending direction	 Normal	 Parallel
Infill	100%	100%
Flexural modulus (MPa)	1965.3 ± 115.5	1680.8 ± 127.9
Maximum force (MPa)	67.3 ± 2.3	72.6 ± 1.0
Deformation (%)	4.3 ± 0.1	4.4 ± 0.1

FILAMENT SPECIFICATIONS		Test Method
Diameter 1.75	1.75 ± 0.05 mm	Innofil3D
Diameter 2.85	2.85 ± 0.10 mm	Innofil3D
Max. roundness deviation 1.75	0.05 mm	Innofil3D
Max. roundness deviation 2.85	0.10 mm	Innofil3D
Net weight on reel	750 g ± 2%	Innofil3D

LIST OF COLORS AND CERTIFICATIONS*						
			Certifications/approvals			
Colour	Code	RAL nr.	10/2011[1]	FDA[2]	2011/65[3]	EN 71-3[4]
Naturel	0001	N/A	Yes	Yes	Yes	Yes
Black	0002	9005	Yes	Yes	Yes	Yes
Red	0004	3020	Yes	No	Yes	Yes
Blue	0005	5002	Yes	Yes	Yes	Yes
Yellow	0006	1003	Yes	Yes	Yes	Yes
Green	0007	6018	Yes	Yes	Yes	Yes
Orange	0009	2008	Yes	No	Yes	Yes
Pink	0020	N/A	Yes	No	Yes	Yes
Silver	0021	9006	Yes	Yes	Yes	Yes

* This overview is generated using information obtained from the raw material suppliers.

Certifications/approvals	Description
[1] Regulation EU No 10/2011:	Union Guidelines on Regulation (EU) No 10/2011 on plastic materials and articles intended to come into contact with food (Europe)
[2] FDA:	Food and Drug administration approval (U.S.A.)
[3] Directive 2011/65/EU:	The restriction of the use of certain hazardous substances in electrical and electronic equipment (Europe)
[4] Directive 2009/48/EC; EN 71-3:	Safety of toys – Part 3: Migration of certain elements (Europe)

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T200 thrusters:

T200 Thruster Documentation

Introduction

The T200 Thruster is a low-cost high performance thruster for marine robotics. It was originally launched in 2014 through a Kickstarter campaign (https://www.kickstarter.com/projects/847478159/the-t100-a-game-changing-underwater-thruster).

Safety

Always practice caution when you're working with electricity in water and with the spinning blades of the propeller. Keep body parts away from the thruster inlet and outlet to avoid injury.

Quick Start

1. Connect motor wires to ESC and connect the ESC to power and a signal.
2. Send a signal and the thruster will start spinning. That's it.

Important Notes

⚠ Do not operate the thruster for extended periods out of water. The bearings are lubricated by the water and vibration and noise will be greater when dry.

⚠ The thruster can handle saltwater and sandy environments pretty well, but it does not get along with seaweed. Avoid sucking seaweed into the thruster to avoid damage.

⚠ Most threadlockers are not chemically compatible with with polycarbonate, and will damage the thrusters if used on any of the screws. Refer to the documentation and chemical compatibility notes of your threadlocker of choice for more information.

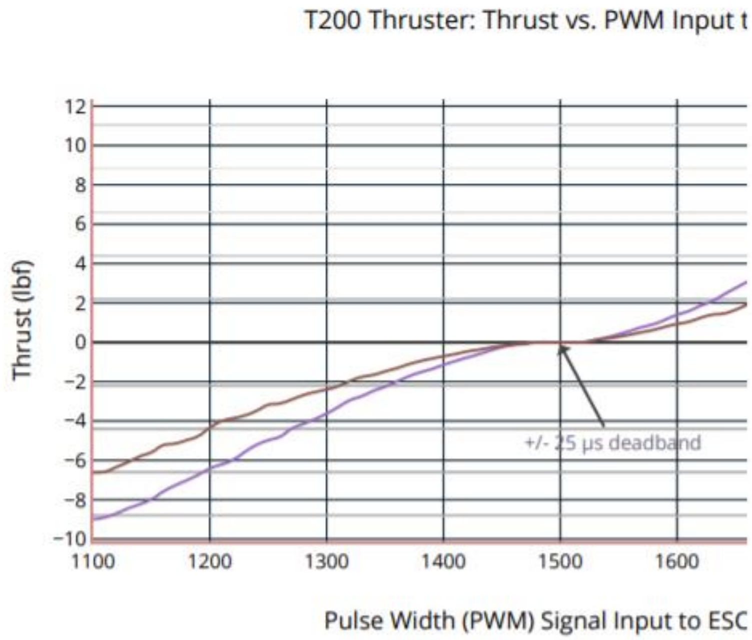
A slight clicking noise is normal, especially when operated dry. It is caused by slight movement of the shaft in the plastic bearings.

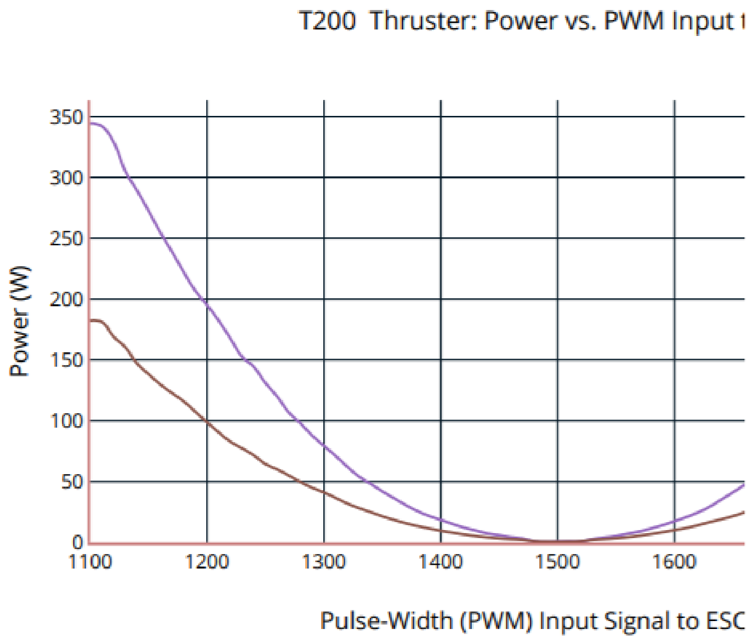
T200 Thruster Specifications

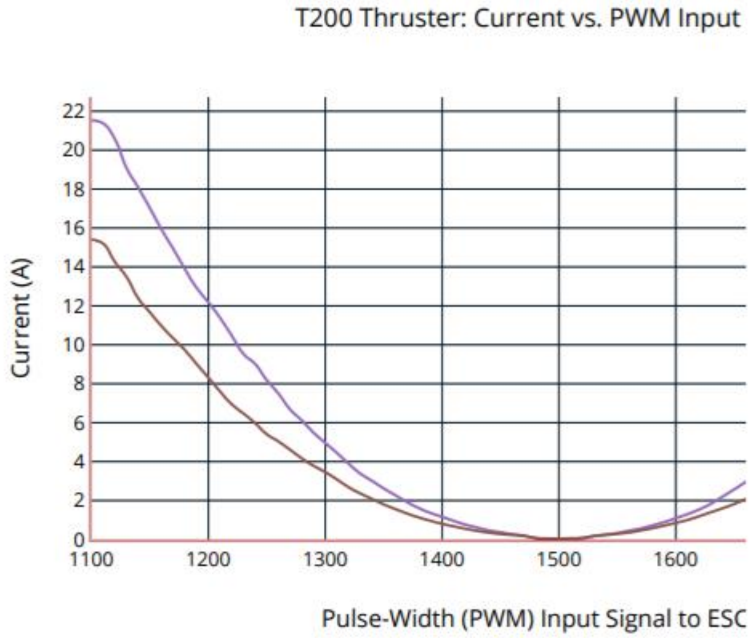
Specification Table

Performance		
Maximum Forward Thrust @ 16V	5.1 kg_f	11.2 lb_f
Maximum Reverse Thrust @ 16V	4.1 kg_f	9.0 lb_f
Maximum Forward Thrust @ 12V	3.55 kg_f	7.8 lb_f
Maximum Reverse Thrust @ 12V	3.0 kg_f	6.6 lb_f
Minimum Thrust	0.01 kg_f	0.02 lb_f
Rotational Speed	300-3800 rev/min	
Electrical		
Operating Voltage	6-20 volts	
Max Current	25 Amps	
Max Power	350 Watts	
Phase Resistance	0.18 +/- 0.01 Ohms	
Phase Inductance (@ 1 kHz)	0.077 +/- 0.008 mH	
Physical		
Length	113 mm	4.45 in
Diameter	100 mm	3.9 in
Weight in Air (with 1m cable)	0.76 lb	344 g
Weight in Water (with 1m cable)	0.34 lb	156 g
Propeller Diameter	76 mm	3.0 in
Mounting Hole Threads	M3 x 0.5	
Mounting Hole Spacing	19 mm	0.75 in
Cable Length	1.0 m	39 in
Cable Diameter	6.3 mm	0.25 in

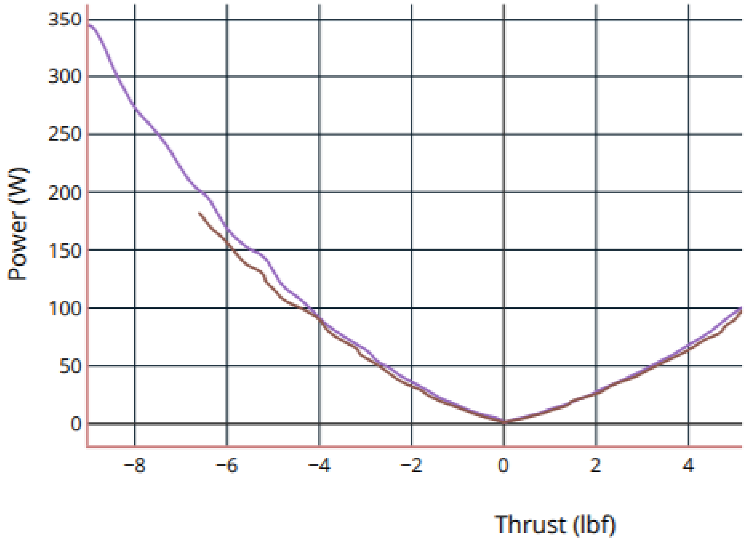
Performance Charts

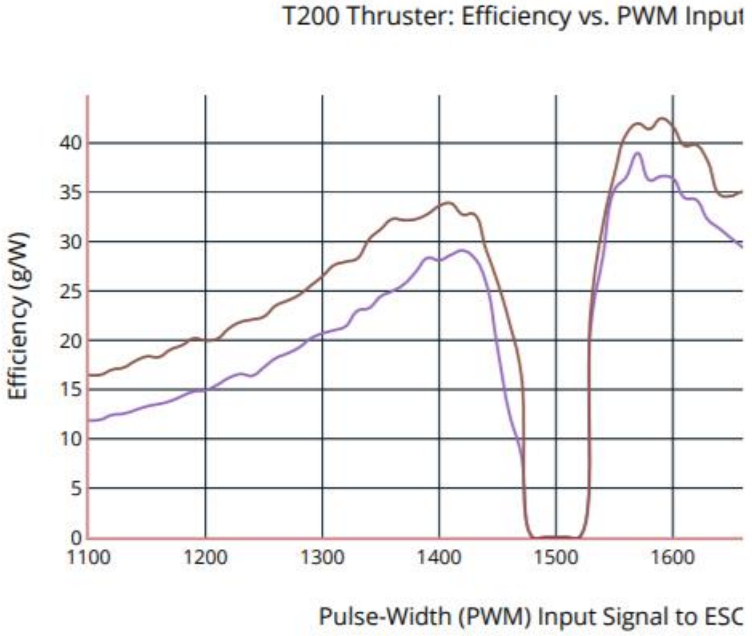

T200 Thruster: Thrust vs. PWM Input t
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
Thrust (lbf)
1100
1200
1300
1400
1500
1600
+/- 25 µs deadband
Pulse Width (PWM) Signal Input to ESC


T200 Thruster: Power vs. PWM Input t
Power (W)
350
300
250
200
150
100
50
0
1100
1200
1300
1400
1500
1600
Pulse-Width (PWM) Input Signal to ESC


T200 Thruster: Current vs. PWM Input
Current (A)
22
20
18
16
14
12
10
8
6
4
2
0
1100
1200
1300
1400
1500
1600
Pulse-Width (PWM) Input Signal to ESC

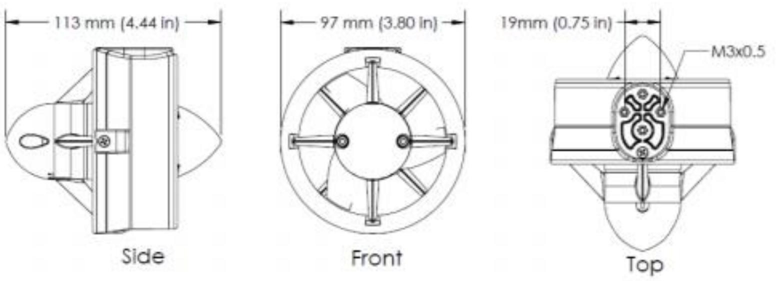
T200 Thruster: Power vs. Thrust





Dimensions

T200 Thruster



3D Model

T200 Thruster

File Type	Link
SolidWorks Part (.sldprt)	T200-THRUSTER-R1.SLDPRT (/thrusters/cad/T200-THRUSTER-R1.SLDPRT)
STEP (.step)	T200-THRUSTER-R1.STEP (/thrusters/cad/T200-THRUSTER-R1.STEP)
IGES (.igs)	T200-THRUSTER-R1.IGS (/thrusters/cad/T200-THRUSTER-R1.IGS)

File Type	Link
STL (.stl)	T200-THRUSTER-R1.STL (/thrusters/cad/T200-THRUSTER-R1.STL)
All Formats in a Zip File (.zip)	T200-THRUSTER-R1.zip (/thrusters/cad/T200-THRUSTER-R1.zip)
T200 Model on GrabCAD	T200 Model on GrabCAD (https://grabcad.com/library/bluerobotics-t200-thruster-1)

Mounting Bracket

File Type	Link
SolidWorks Part (.sldprt)	T100-P-BRACKET-R1.SLDPRT (/thrusters/cad/T100-P-BRACKET-R1.SLDPRT)
STEP (.step)	T100-P-BRACKET-R1.STEP (/thrusters/cad/T100-P-BRACKET-R1.STEP)
IGES (.igs)	T100-P-BRACKET-R1.IGS (/thrusters/cad/T100-P-BRACKET-R1.IGS)
STL (.stl)	T100-P-BRACKET-R1.STL (/thrusters/cad/T100-P-BRACKET-R1.STL)
All Formats in a Zip File (.zip)	T100-P-BRACKET-R1.zip (/thrusters/cad/T100-P-BRACKET-R1.zip)

Installation

The T200 Thruster is easy to install in many different applications. It was designed with versatile mounting options for a variety of different applications. It includes a counter-rotating set of propellers. Check out the tutorial on how to change the propeller.

Changing the Propeller

Changing the Propeller ➲ (/tutorials/changing-the-propeller/)

Mounting Options

The T200 Thruster has several mounting options. The nozzle has four mounting holes that can be used to secure directly to vehicle.

Occasionally, these holes may not be convenient or it may be difficult to secure the screws. In this case, the mounting bracket may be a better option. The mounting bracket is secured to the thruster through the four screw holes. It can be mounted in two different orientation as shown below.

Thruster with bracket in front/back orientation

Thruster with bracket in side to side orientation

The mounting bracket also includes a guide hole that can be drilled out with a 1/4" (6.5mm) drill bit to allow the wire to pass directly through the bracket.

Which mounting option you choose depends on your application.

Electrical Connections

Connecting to an External ESC

The thruster has a cable containing three wires. These three wires must be connected to the three motor wires on the electronic speed controller (ESC). The order does not matter, but if the motor direction is the reverse of what is desired, switch two of the wires.

The three wires in the cable (green, white, blue) are always connected to the same motor phases, so connecting the colors in a consistent fashion will result in all motors rotating in the same direction.

How to Cut and Strip the Cable

The thruster comes with a tough urethane-jacketed cable. This is great for use underwater, but it can be a little difficult to remove the jacket from the wires if you want to cut the cable to a shorter length. During production, we use a thermal wire strippers, but the jacket can also be removed with a razor blade or hobby knife. Check out the cable stripping tutorial with pictures here.

Cable Jacket Stripping ➋ (/tutorials/cable-stripping/)

Operation

The thruster requires a brushless electronic speed controller (ESC). Checkout our Basic ESC documentation page for more information.

Basic ESC ➋ (/besc/)

Important: Do not operate the thruster for extended periods out of water. The bearings are lubricated by the water and vibration and noise will be greater when dry.

Clicking Noise

If you hear a clicking noise during operation, especially when operating in air, do not be alarmed. It's normal.

The thruster uses solid plastic bushings and due to the tolerances of the bushings and motors shafts, the shaft can move slightly in the bearing. The noise is drastically reduced or eliminated when operated in water. The water acts as a lubricant for the bearings and smooths operation.

Care and Maintenance

The T200 Thruster does not require much maintenance.

Normal Care

During normal use:

- Rinse with fresh water after use in saltwater to minimize the accumulation of salt deposits.
- Rinse after operating in sandy environments to remove sand particles.

If operated for extended periods in the water:

- Occasionally clean biological fouling and mineral deposits from the thruster or performance may be impacted.

Disassembly/Assembly

You may need to take apart your thruster from time to time - or maybe you just want to take a peek at the inner workings of the T200! Either way, this tutorial illustrates how.

Disassembly/Assembly (/tutorials/disassembly-assembly/)

Troubleshooting

The motor does not start

This is usually an issue with the proper commands being sent to the ESC. Please see the ESC documentation (/besc/) for instructions on how to operate the ESC properly.

The motor does not start but the propeller tries to move.

This can be caused by a disconnected motor wire or a short between motor wires. Check that all three motor wires are connected and not shorting. To do this, check resistance of each phase pair in the thruster. Each thruster wire phases pair (Blue/green. blue/white, green/white) should have the same resistance within 0.1-0.2ohms or so. If no connection is read or one pair has significantly higher resistance, your thruster has a fault. Please e-mail support@bluerobotics.com (mailto:support@bluerobotics.com) if this fault is found.

The motor is jammed when turned by hand.

This can be caused by something jamming the propeller or by major internal damaged caused by overheating, short circuits, or heavily worn bearings. Please disassemble the thruster and inspect for damage or blockage.

Details

For all the engineers out there, here's some more info.

Comparison to T100

Test Results

- **Endurance Testing.** We have tested the T200 Thruster for up to 300 hours continuous operation at full throttle power.
- **Sand and Particulate Testing.** The thrusters handle small particulate matter very well. See this video (https://www.youtube.com/watch?v=0X0EncNR8I8) of testing the thrusters in heavy sand.
- **Depth Testing.** As of writing, the thrusters have been tested to a maximum depth of 3000m (4500 psi) in static conditions. This testing was performed by Woods Holes Oceanographic Institution and you can read more about it here (http://www.bluerobotics.com/pressure-testing-3000m-depth/).

Quality Control

We perform the following tests on every thruster before they are shipped.

- **Insulation Test**, also know as a hipot test. We submerge the thruster in water and measure current leakage at high voltage (250V) to ensure that the insulation is sufficient.
- **Spin Test**. The thruster is operated in air across the entire speed range to ensure that it operates correctly.
- **Visual Inspection**. Each thruster is inspected for visual issues or damage.

Painting the Thruster

If you want the thruster to match the color scheme of your vehicle, you can paint the propeller and other components. We have tested Tamiya Spray Paint for Polycarbonate (http://www.tamiyausa.com/items/paints-amp-finishes-60/spray-ps-(polycarbonate)-61700) which comes in many colors and works well on the plastic.

Bilge Motor:

DATA SHEET ELECTRIC BILGE PUMP

First Issued: 2013-08-29

Pump	:	**Electrically operated direct-curent bilge pump**
Application	:	**Removing bilge water from small craft with a hull length up to 24 m.**
Features	:	Durable snap connection for easy cleaning
		Double seals for a long life time
		Internal components in contact with bilge water are corrosion resistant or made of stainless steel
		Silent running and smooth operation, May run dry without damage,
		Suitable for continuous duty cycle
		Suitable for fresh, salt water and other fluids which may normally present in the bilge
Construction	:	Centrifugal pump with permanent magnet DC motor
Material, pump housing	:	Plastic
impeller	:	plastic
Protection	:	IP 67
Length connection cable	:	1.2 m (4 ft)
Temperature	:	Suitable for use in the range 0 to 50 degrees C. (32 to 122 degrees F.)

Specifications,

Type		**BLP12500**	**BLP121000**	**BLP122000**	**BLP123000**
Voltage, nominal		12 V DC			
Current, with a voltage of 13.6 V and a discharge head of 0 m (0 ft)		4.5 A	4.5 A	9 A	13 A
with a voltage of 13.6 V and a maximum discharge head		3 A	3 A	6 A	9 A
Capacity with 13,6 V and rise of	**0 m (0 ft)**	40 l/min (530 GPH Imp) (635 GPH US)	50 l/min (660 GPH Imp) (795 GPH US)	110 l/min (1450 GPH IMP) (1745 GPH US)	160 l/min (2110 GPH IMP) (2535 GPH US)
	1 m (3.3 ft)	40 l/min (530 GPH Imp) (635 GPH US)	50 l/min (660 GPH Imp) (795 GPH US)	105 l/min (1385 GPH IMP) (1665 GPH US)	150 l/min (1980 GPH IMP) (2380 GPH US)
	2 m (3.7 ft)	37 l/min (490 GPH Imp) (585 GPH US)	43 l/min (570 GPH Imp) (680 GPH US)	70 l/min (925 GPH IMP) (1110 GPH US)	125 l/min (1650 GPH IMP) (1980 GPH US)
Maximum rise		4 m (13 ft)	4 m (13 ft)	4 m (13 ft)	5 m (16 ft)
Connections for hose		19 mm (3/4")	28.5 mm (1 1/8")	28.5 mm (1 1/8")	32 mm (1 1/4")
Strainer, max. particle size		3 mm (1/8")		5 mm (3/16")	4.5 mm (3/16")
Weight		0.65 kg (1 lbs 7 oz)	0.65 kg (1 lbs 7 oz)	1.25 kg (2 lbs 12 oz)	2.2 kg (4 lbs 14 oz)

Relevant CE Standards	:	EN 55014-1, -2 (EMC - Emission, Immunity)
		EN ISO 15083 (RCD - Bilge pump systems), ISO 8846 Marine (Ignition protection)
Certification	:	DCI-RCD
Classification	:	Non

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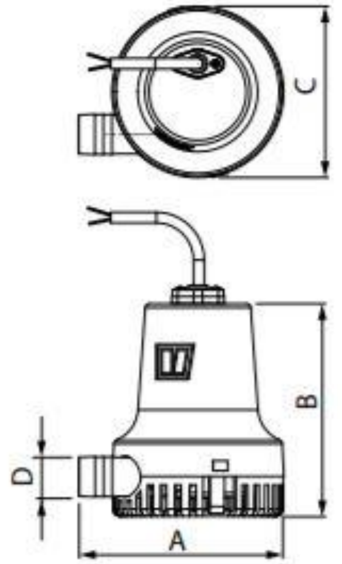
TELEFAX: +31 10 4372673 - 4621286 - E-MAIL: sales@vetus.nl - INTERNET: http://www.vetus.com
DS_011_009_BLP_500_3000
Rev.: 2013-08-30 page 1 of 2



Overall dimensions

	A		B		C		D	
BLP12500	115	(4 1/2")	120	(4 3/4")	90	(3 9/16")	19	(3/4")
BLP121000							28.5	(1 1/8"
BLP122000	145	(5 11/16")	150	(5 7/8")	120	(4 3/4")	28.5	1 1/8"
BLP123000	170	(6 11/16")	180	(7 1/16")	130	(5 1/8")	32	1 1/4"

Electrical Subsystem:

Bar30 (Pressure sensor):

Bar30 Pressure Sensor Documentation

Introduction

The *Bar30* is a high resolution, water proof pressure and temperature sensor that comes in a Blue Robotics penetrator which provides a waterproof, high-pressure seal for your enclosure.

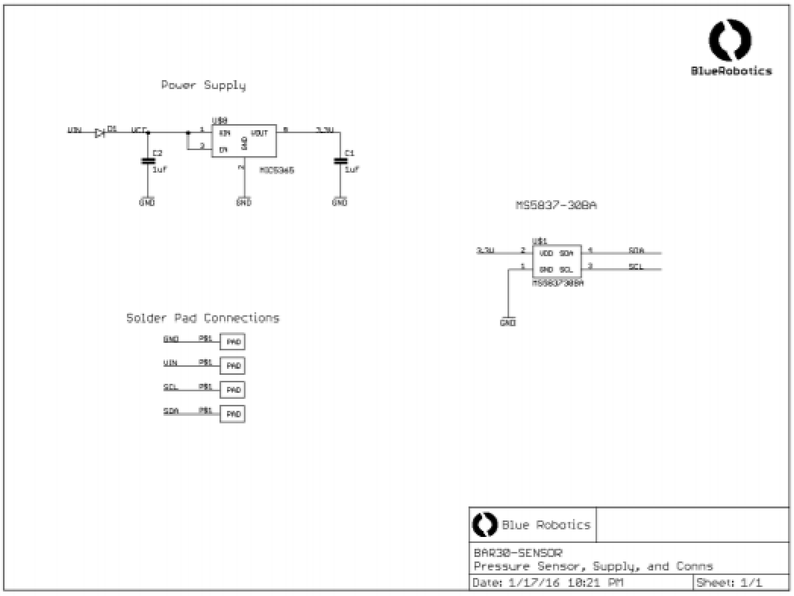
Quick Start

1. Download MS5837 Arduino Library (https://github.com/bluerobotics/BlueRobotics_MS5837_Library).
2. Install software such as the Example Code to your microcontroller.
3. Connect the DF13 or bare wires to the appropriate microcontroller pins, using a logic level converter (https://www.bluerobotics.com/store/electronics/level-converter-r1/) if your board has 5V logic:
   - Green: SCL (3.3V logic)
   - White: SDA (3.3V logic)
   - Red: +2.5-5.5V
   - Black: Ground

Specifications

Schematic

The EagleCAD files (https://github.com/bluerobotics/Bar30-Pressure-Sensor) for the schematic and board are available on our GitHub page (https://github.com/bluerobotics).



(/bar30/cad/BAR30-SENSOR-Schematic.png)

Bar30 Schematic.png (/bar30/cad/BAR30-SENSOR-Schematic.png)

Specification Table

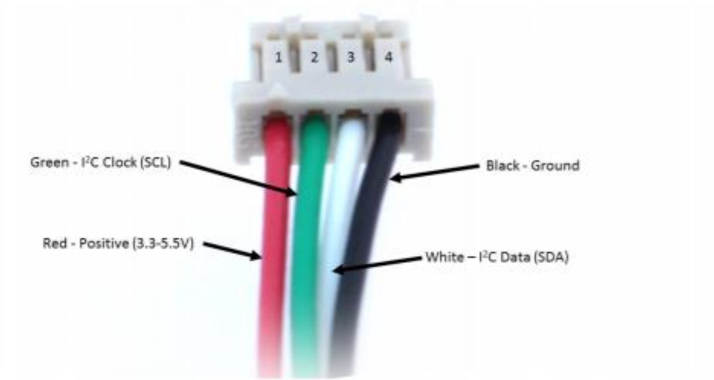
For further information please see the MS5837-30BA Data Sheet. (http://www.te.com/commerce/DocumentDelivery/DDEController?Action=showdoc&DocId=Data+Sheet%7FMS5837-30BA%7FB1%7Fpdf%7FEnglish%7FENG_DS_MS5837-30BA_B1.pdf%7FCAT-BLPS0017)

Electrical		
Item	**Condition**	**Value**
Supply Voltage	-	2.5-5.5 volts
I^2C Logic Voltage (SDA and SCL)	-	2.5 - 3.6 volts
Peak Current	-	1.25 mA
Pressure		
Item	**Condition**	**Value**
Maximum Mechanical Pressure	-	50 bar
Operating Pressure	-	0-30 bar [up to 1000 ft (300 m) in water]
Absolute Accuracy (0-40°C)	From 0-6 bar	+/- 50 mbar (51 cm in freshwater)
	From 0-20 bar	+/- 100 mbar (102 cm in freshwater)
	From 0-30 bar	+/- 200 mbar (204 cm in freshwater)
Absolute Accuracy (-25-85°C)	From 0-6 bar	+/- 100 mbar (102 cm in freshwater)
	From 0-20 bar	+/- 200 mbar (204 cm in freshwater)

Electrical		
	From 0-30 bar	+/- 400 mbar (408 cm in freshwater)
Temperature		
Item	**Condition**	**Value**
Operating Temperature	-	-20 to +85°C
Storage Temperature	-	-40 to +85°C
Absolute Accuracy	From 0-10 bar at 0-60°C	+/- 1.5°C
	From 0-30 bar at -20-85°C	+/- 4.0°C
Physical		
Wire Colors	Green - I^2C Clock (SCL, 3.3V)	
	White - I^2C Data (SDA, 3.3V)	
	Red - Positive (2.5-5.5V)	
	Black - Ground	
Overall Length	37 mm	
Thread Size	M10x1.5 20 mm threaded	
Recommended Through Hole Size	10-11 mm	
Wrench Flats	16 mm	

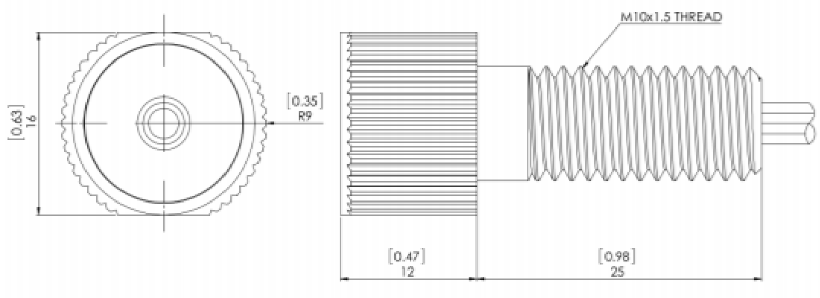
DF13 Pinout

1 Δ	Red - Positive (3.3-5.5V)
2	Green - I^2C Clock (SCL)
3	White - I^2C Data (SDA)
4	Black - Ground



Mating Connector: Hirose 4-pos DF13 on Digi-Key (http://www.digikey.com/product-detail/en/DF13-4P-1.25DSA/H2193-ND/241767)

2D Drawing



3D Model

All 3D models are provided in zip archives containing the follow file types:

- SolidWorks Part (.sldprt)
- IGES (.igs)
- STEP (.step)
- STL (.stl)

Bar 30 Pressure Sensor		
Bar30 Pressure Sensor	BAR30-PRESSURE-SENSOR-R1.zip (/bar30/cad/BAR30-PRESSURE-SENSOR-R1.zip)	
Bar30 Penetrator Nut	PENETRATOR-M-NUT-10-A-R2.zip (http://www.bluerobotics.com/models/PENETRATOR-M-NUT-10-A-R2.zip)	

Installation

Step 1: Lubricating the O-ring

Use a small amount of silicone grease on the O-ring for lubrication and place it in the groove of the Bar30 Pressure Sensor.

Step 2: Installation

Install the Bar30 Pressure Sensor into an endcap and tighten by hand or with a wrench.

Example Code

Arduino

This example uses the BlueRobotics MS5837 Library (https://github.com/bluerobotics/BlueRobotics_MS5837_Library) with the connected sensor. The example reads the sensor and prints the resulting values to the serial terminal.

Please remember to use a logic level converter, such as this one (http://bluerobotics.com/store/electronics/level-converter-r1/), to convert Arduino 5V levels to 3.3V!

If you've never used Arduino before, we suggest checking out some tutorials! (https://www.arduino.cc/en/Tutorial/HomePage)

```
#include <Wire.h>
#include "MS5837.h"

MS5837 sensor;

void setup() {

  Serial.begin(9600);

  Serial.println("Starting");

  Wire.begin();

  sensor.init();

  sensor.setFluidDensity(997); // kg/m^3 (997 freshwater, 1029 for seawater)
}

void loop() {

  sensor.read();

  Serial.print("Pressure: ");
  Serial.print(sensor.pressure());
  Serial.println(" mbar");

  Serial.print("Temperature: ");
  Serial.print(sensor.temperature());
  Serial.println(" deg C");

  Serial.print("Depth: ");
  Serial.print(sensor.depth());
  Serial.println(" m");

  Serial.print("Altitude: ");
  Serial.print(sensor.altitude());
  Serial.println(" m above mean sea level");

  delay(1000);
}
```

Python

This example uses the BlueRobotics MS5837 Python Library (https://github.com/bluerobotics/ms5837-python) with the sensor connected to a Raspberry Pi. The Raspberry Pi uses 3.3V logic levels on the I2C pins, so a logic level shifter is not required.

```
import ms5837
import time

sensor = ms5837.MS5837_30BA() # Default I2C bus is 1 (Raspberry Pi 3)

# We must initialize the sensor before reading it
if not sensor.init():
        print "Sensor could not be initialized"
        exit(1)

# Print readings
while True:
        if sensor.read():
                print("P: %0.1f mbar  %0.3f psi\tT: %0.2f C  %0.2f F") % (
                sensor.pressure(), # Default is mbar (no arguments)
                sensor.pressure(ms5837.UNITS_psi), # Request psi
                sensor.temperature(), # Default is degrees C (no arguments)
                sensor.temperature(ms5837.UNITS_Farenheit)) # Request Farenheit
        else:
                print "Sensor read failed!"
                exit(1)
```

Intel NUC:

Intel® NUC Board NUC7i5DNBE

Add to Compare

Essentials

Export specifications

Product Collection	Intel® NUC Board with 7th Generation Intel® Core™ Processors
Code Name	Products formerly Dawson Canyon
Status	Launched
Launch Date ?	Q3'17
Board Form Factor	UCFF (4" x 4")
Socket	Soldered-down BGA
Internal Drive Form Factor	M.2 and 2.5" Drive
# of Internal Drives Supported	2
TDP ?	15 W
DC Input Voltage Supported	12-24 VDC
Recommended Customer Price ?	$384.00
Processor Included	Intel® Core™ i5-7300U Processor (3M Cache, up to 3.50 GHz)
Warranty Period	3 yrs

Supplemental Information

Embedded Options Available ?	Yes
Description	7th Gen Commercial Intel® NUC

Memory & Storage

Max Memory Size (dependent on memory type) ?	32 GB
Memory Types ?	DDR4-2133 1.2V SO-DIMM
Max # of Memory Channels ?	2
Max # of DIMMs ?	2
ECC Memory Supported ‡ ?	No

Processor Graphics

Integrated Graphics ‡ ?	Yes
Graphics Output ?	Dual HDMI 2.0a, 4-lane eDP 1.4
# of Displays Supported ‡	3

Expansion Options

PCI Express Revision	Gen 3
PCI Express Configurations ‡	PCIe x4: M.2 22x80 (key M) slot PCIe x1: M.2 22x30 (key E) slot
M.2 Card Slot (wireless)	22x30 (key E) slot
M.2 Card Slot (storage)	22x80 (key M) slot

I/O Specifications

# of USB Ports	4
USB Configuration	2x front and 2x rear USB 3.0; 1x USB 3.0 and 2x USB 2.0 via internal headers
USB Revision	2.0, 3.0
USB 2.0 Configuration (External + Internal)	0 + 2
USB 3.0 Configuration (External + Internal)	2B 2F +1
Total # of SATA Ports	2
Max # of SATA 6.0 Gb/s Ports	2
RAID Configuration	2.5" HDD/SSD + M.2 SATA/PCIe SSD (RAID-0 RAID-1)
Serial Port via Internal Header	Yes
Integrated LAN	Intel® i219-LM 10/100/1000 Mbps Ethernet
Additional Headers	Front_panel (PWR, RST, 5V, 5Vsby, 3.3Vsby); HDMI_CEC; Internal 2x2 power connector

Advanced Technologies

Intel® Optane™ Memory Supported ‡	Yes
Intel® Virtualization Technology for Directed I/O (VT-d) ‡	Yes
Intel® vPro™ Platform Eligibility ‡	Yes
Intel® ME Firmware Version	v11.7
TPM	Yes
TPM Version	2.0
Intel® Rapid Storage Technology	Yes
Intel® Virtualization Technology (VT-x) ‡	Yes
Intel® Platform Trust Technology (Intel® PTT)	No

Security & Reliability

Intel® AES New Instructions	Yes
Intel® Trusted Execution Technology ‡	Yes

Battery:

Item specifics

Use: Vehicles & Remote Control Toys

For Vehicle Type: Helicopters

Remote Control Peripherals/Devices: Battery

RC Parts & Accs: Batteries - LiPo

Material: Composite Material

Technical parameters: Value 10

Size: 165*64*42mm

Tool Supplies: Battery

Model Number: HRB 14.8V 10000MAh 25C 4S

Four-wheel Drive Attributes: Battery

Brand Name: YOWOO POWER

Upgrade Parts/Accessories: Battery

Product Description

INTRODUCTION

BRAND INTRODUCTION

HRB Company founded in 2013, is a leading manufacturer of RC LiPo Battery based on Shenzhen China. HRB Batteries offer an excellent value by providing factory direct pricing and quality that meets or exceeds that of other major battery manufacturers. All of our HRB batteries comply with RoHS and CE quality testing standards.

We only use Grade A cell for you.

HRB RC Battery 14.8V 10000mAh 25C Max 50C Lipo Battery For DJI S800 Drones Helicopters Robots

DESCRIPTION

PRODUCT DESCRIPTION

<

Brand	**HRB Battery**
Nominal Voltage	**14.8V**
Nominal Capacity	**10000mAh**
Continuous discharge rate	**25C**
Burst Rate	**50C**
Voltage per cell	**3.7V**
Max voltage per cell	**4.2V**
Cells	**4S**
Suggest charge rate	**1C**
Silicone wire	**10awg**
Plug Type	**Deans Plug,XT60,EC5,Traxxas,XT90,XT150**
Certificate	**CE,ROHS,MSDS,UN38.3**
Warranty	**12months**
Size	**165 x 64 x 42mm (±0-3mm) /1pc**
Weight	**834g ± 2g /1pc**
Packing list	**1pc x 14.8V 10000mAh 25C Lipo Battery**

We have different type of lipo battery for your device or project. From 10C to 60C with different working/discharge rate, capacity from 300mAh~20000mAh per cell .

Please contact with us ensure the battery /battery pack max.size and working data, then we help you ensure the best solution for power batteries.

Caution:

Don't over charge more than 4.2V and don't over discharge below 3.7V
Don't put it beside the high temperature condition.
Don't throw it into fire.
Don't throw it into water.

SHOW

PRODUCT SHOW

Packaging Details

nit Type: piece

ackage Size: 15cm x 16cm x 15cm (5.91in x 6.30in x 5.91in)

Package Weight: 1.3kg (2.87lb.)

PixHawk (Main Control Unit):

Pixhawk 1 Flight Controller

The *Pixhawk®* *1* autopilot is a popular general purpose flight controller based on the Pixhawk-project **FMUv2** open hardware design (it combines the functionality of the PX4FMU + PX4IO). It runs PX4 on the NuttX OS.

> Originally manufactured by 3DR® this board was the original standard microcontroller platform for PX4. While the board is no longer manufactured by 3DR, you can use the mRo Pixhawk as a drop-in replacement.

Assembly/setup instructions for use with PX4 are provided here: Pixhawk Wiring Quickstart

Key Features

- Main System-on-Chip: STM32F427
    - CPU: 180 MHz ARM® Cortex® M4 with single-precision FPU
    - RAM: 256 KB SRAM (L1)
- Failsafe System-on-Chip: STM32F100
    - CPU: 24 MHz ARM Cortex M3
    - RAM: 8 KB SRAM
- Wifi: ESP8266 external
- GPS: U-Blox® 7/8 (Hobbyking®) / U-Blox 6 (3D Robotics)
- Optical flow: PX4 Flow unit
- Redundant power supply inputs and automatic failover
- External safety switch
- Multicolor LED main visual indicator
- High-power, multi-tone piezo audio indicator
- microSD card for high-rate logging over extended periods of time

Connectivity

- 1x I2C
- 1x CAN (2x optional)
- 1x ADC
- 4x UART (2x with flow control)
- 1x Console
- 8x PWM with manual override
- 6x PWM / GPIO / PWM input
- S.BUS / PPM / Spektrum input
- S.BUS output

Where to Buy

Originally manufactured by 3DR® this board was the original standard microcontroller platform for PX4®. While the board is no longer manufactured by 3DR, you can use the mRo Pixhawk as a drop-in replacement.

Order mRo Pixhawk from:

- Bare Bones - Just the board (useful as a 3DR Pixhawk replacement)
- mRo Pixhawk 2.4.6 Essential Kit - includes everything except for telemetry radios
- mRo Pixhawk 2.4.6 Cool Kit! (Limited edition) - includes everything you need including telemetry radios

If out of stock the software-compatible but not connector-compatible versions can be used:

- HKPilot32

Specifications

Processor

- 32bit STM32F427 Cortex-M4F core with FPU
- 168 MHz
- 256 KB RAM
- 2 MB Flash
- 32 bit STM32F103 failsafe co-processor

Sensors

- ST Micro L3GD20H 16 bit gyroscope
- ST Micro LSM303D 14 bit accelerometer / magnetometer
- Invensense MPU 6000 3-axis accelerometer/gyroscope
- MEAS MS5611 barometer

Interfaces

- 5x UART (serial ports), one high-power capable, 2x with HW flow control
- 2x CAN (one with internal 3.3V transceiver, one on expansion connector)
- Spektrum DSM / DSM2 / DSM-X® Satellite compatible input
- Futaba S.BUS® compatible input and output
- PPM sum signal input
- RSSI (PWM or voltage) input
- I2C
- SPI
- 3.3 and 6.6V ADC inputs
- Internal microUSB port and external microUSB port extension

Power System and Protection

- Ideal diode controller with automatic failover
- Servo rail high-power (max. 10V) and high-current (10A+) ready
- All peripheral outputs over-current protected, all inputs ESD protected

Voltage Ratings

Pixhawk can be triple-redundant on the power supply if three power sources are supplied. The three rails are: Power module input, servo rail input, USB input.

Normal Operation Maximum Ratings

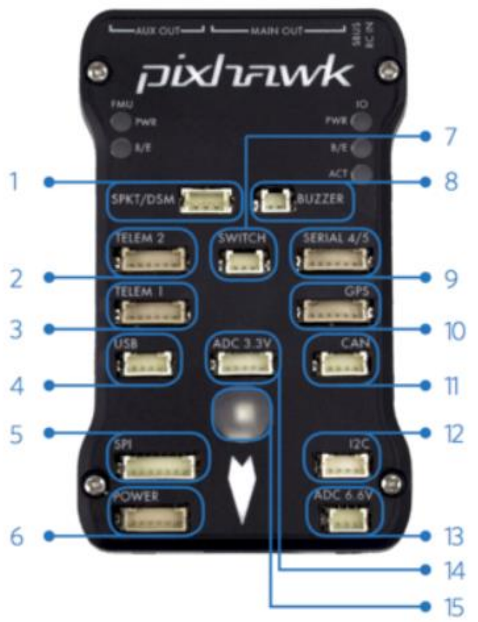
Under these conditions all power sources will be used in this order to power the system

- Power module input (4.8V to 5.4V)
- Servo rail input (4.8V to 5.4V) **UP TO 10V FOR MANUAL OVERRIDE, BUT AUTOPILOT PART WILL BE UNPOWERED ABOVE 5.7V IF POWER MODULE INPUT IS NOT PRESENT**
- USB power input (4.8V to 5.4V)

Absolute Maximum Ratings

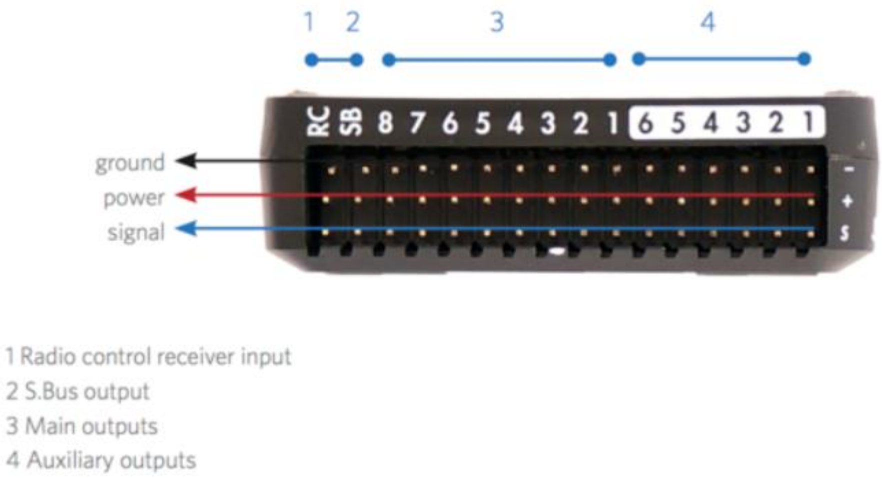
Under these conditions the system will not draw any power (will not be operational), but will remain intact.

- Power module input (4.1V to 5.7V, 0V to 20V undamaged)
- Servo rail input (4.1V to 5.7V, 0V to 20V)
- USB power input (4.1V to 5.7V, 0V to 6V)



1 Spektrum DSM receiver
2 Telemetry (radio telemetry)
3 Telemetry (on-screen display)
4 USB
5 SPI (serial peripheral interface) bus
6 Power module
7 Safety switch button
8 Buzzer
9 Serial
10 GPS module
11 CAN (controller area network) bus
12 I²C splitter or compass module
13 Analog to digital converter 6.6 V
14 Analog to digital converter 3.3 V
15 LED indicator

1 Input/output reset button
2 SD card
3 Flight management reset button
4 Micro-USB port



Pinouts

TELEM1, TELEM2 ports

Pin	Signal	Volt
1 (red)	VCC	+5V
2 (blk)	TX (OUT)	+3.3V
3 (blk)	RX (IN)	+3.3V
4 (blk)	CTS (IN)	+3.3V
5 (blk)	RTS (OUT)	+3.3V
6 (blk)	GND	GND

GPS port

Pin	Signal	Volt
1 (red)	VCC	+5V
2 (blk)	TX (OUT)	+3.3V
3 (blk)	RX (IN)	+3.3V
4 (blk)	CAN2 TX	+3.3V
5 (blk)	CAN2 RX	+3.3V
6 (blk)	GND	GND

SERIAL 4/5 port - due to space constraints two ports are on one connector.

Pin	Signal	Volt
1 (red)	VCC	+5V
2 (blk)	TX (#4)	+3.3V
3 (blk)	RX (#4)	+3.3V
4 (blk)	TX (#5)	+3.3V
5 (blk)	RX (#5)	+3.3V
6 (blk)	GND	GND

ADC 6.6V

Pin	Signal	Volt
1 (red)	VCC	+5V
2 (blk)	ADC IN	up to +6.6V
3 (blk)	GND	GND

ADC 3.3V

Pin	Signal	Volt
1 (red)	VCC	+5V
2 (blk)	ADC IN	up to +3.3V
3 (blk)	GND	GND
4 (blk)	ADC IN	up to +3.3V
5 (blk)	GND	GND

I2C

Pin	Signal	Volt
1 (red)	VCC	+5V
2 (blk)	SCL	+3.3 (pullups)
3 (blk)	SDA	+3.3 (pullups)
4 (blk)	GND	GND

CAN

Pin	Signal	Volt
1 (red)	VCC	+5V
2 (blk)	CAN_H	+12V
3 (blk)	CAN_L	+12V
4 (blk)	GND	GND

SPI

Pin	Signal	Volt
1 (red)	VCC	+5V
2 (blk)	SPI_EXT_SCK	+3.3
3 (blk)	SPI_EXT_MISO	+3.3
4 (blk)	SPI_EXT_MOSI	+3.3
5 (blk)	!SPI_EXT_NSS	+3.3
6 (blk)	!GPIO_EXT	+3.3
7 (blk)	GND	GND

POWER

Pin	Signal	Volt
1 (red)	VCC	+5V
2 (blk)	VCC	+5V
3 (blk)	CURRENT	+3.3V
4 (blk)	VOLTAGE	+3.3V
5 (blk)	GND	GND
6 (blk)	GND	GND

SWITCH

Pin	Signal	Volt
1 (red)	VCC	+3.3V
2 (blk)	!IO_LED_SAFETY	GND
3 (blk)	SAFETY	GND

Console Port

The system's serial console runs on the port labeled SERIAL4/5. The pinout is standard serial pinout, to connect to a standard FTDI cable (3.3V, but its 5V tolerant).

Please refer to the Devguide wiring page for details of how to wire up this port.

Build Firmware

To build (and upload) PX4 firmware for this board:

```
make px4fmu-v2_default upload
```

Parts / Housings

- **ARM MINI JTAG (J6**, //not populated per default//**)**: 1.27 mm 10pos header (SHROUDED, for Black Magic Probe: FCI 20021521-00010D4LF (Distrelec, Digi-Key,) or Samtec FTSH-105-01-F-DV-K (untested) or Harwin M50-3600542 (Digikey or Mouser)
  - JTAG Adapter Option #1: BlackMagic Probe, comes without cables, needs the **Samtec FFSD-05-D-06.00-01-N** cable (Samtec sample service or Digi-Key Link: SAM8218-ND) or Tag Connect Ribbon and a Mini-USB cable
  - JTAG Adapter Option #2: Digi-Key Link: ST-LINK/V2 / ST USER MANUAL, needs an ARM Mini JTAG to 20pos adapter: Digi-Key Link: 726-1193-ND
  - JTAG Adapter Option #3: SparkFun Link: Olimex ARM-TINY or any other OpenOCD-compatible ARM Cortex JTAG adapter, needs an ARM Mini JTAG to 20pos adapter: Digi-Key Link: 726-1193-ND
- **USARTs**: Hirose DF13 6 pos (Digi-Key Link: DF13A-6P-1.25H(20))
  - Mates: Hirose DF13 6 pos housing (Digi-Key Link: Hirose DF13-6S-1.25C)
- **I2C and CAN**: Hirose DF13 4 pos (Digi-Key Link: DF13A-4P-1.25H(20))
  - Mates: Hirose DF13 4 pos housing (Digi-Key Link: Hirose DF13-4S-1.25C)
- **USB (J5)**: Micro USB-B
  - Mates: Cell phone data / charger cables, e.g. Digi-Key Link: ASSMANN AK67421-0.5-R

Supported Platforms / Airframes

Any multicopter / airplane / rover or boat that can be controlled with normal RC servos or Futaba S-Bus servos.

Fixed camera:

Item Description

Viewing Angle (Degree)	90°
Alarm Action	Local Alarm
Technology	Infrared
Clarity	720P
Sensor	CCD
Model Number	CR-006A30M
Installation	Normal
Storage	None
Supported Operating Systems	Windows 10,Windows 7,Windows Vista,Window...
Horizontal Resolution	800TVL
Plug Type	EU Plug
Supported Mobile Systems	Android,iOS
Sensor Size	1/4"
Brand Name	ccthook
Audio Output	1CH RCA
Focal Length	6mm

Signal System	PAL
Power Supply	Normal
Sensor Brand	SONY
underwater camera,	fishing camera
Waterproof camera	fish finder
Underwater fishing camera	Diving camera
Camera case material	strong plastic
Camera glass material	sapphir glass
sensor size	1/3 inch CCD or CMOS
camera led light	24PCS white LEDS, Leds adjustable
Cable length	20/30/50/100 meters, (up to 300m available)
Viewing Angle (Degree)	90degree
Supported Mobile Systems	iPhone OS

Products Description:

Underwater camera, fishing camera, Waterproof camera, fish finder, Underwater fishing camera, Diving camera

Camera specification:

1. camera size: 180mm x 100mm
2. Camera case material: strong plastic
3. Camera glass material: sapphir glass
4. sensor size: 1/3 inch CCD or CMOS
5. Total Pixels: 600 TVL
6. view angle: 92°
7. camera led light: 24PCS white LEDS
8. Leds adjustable
9. Cable length: 20/30/50/100 meters, (up to 300m available)
10. camerawork current: 100MA
11. camera power supply:DC 12V
12. Work condition: underwater

Rotating Camera:

Item Description

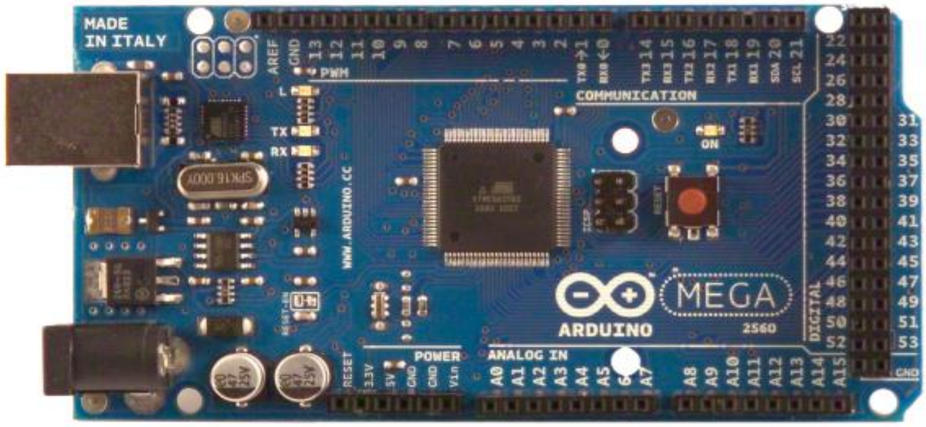
Minimum Illumination(Lux)	0.2lux
Alarm Action	Local Alarm
Model Number	CR-006C30M
Supported Operating Systems	No
Sensor	CMOS
Installation	Normal
Storage	None
Type	Analog Camera
Video Compression Format	MJPEG
Wall Bracket	Side
Viewing Angle (Degree)	360°
is_customized	Yes
Color	Black
Dimensions (L x W x D)(mm)	135mm x 85mm
Supported Mobile Systems	Android
Technology	Pan / Tilt / Zoom

,Audio Output	1CH RCA
Special Features	Waterproof / Weatherproof
IR Distance(m)	10meters
Connectivity	Closed System/CCTV Wired
Style	Dome Camera
High Definition	None
Power Supply	Normal
Power Supply(V)	12V
Network Interface	None
Sensor Brand	SONY
Lens (mm)	3.6mm
Power Consumption(W)	1W
underwater camera,	fishing camera
Waterproof camera	fish finder
Underwater fishing camera	Diving camera
Camera case material	strong plastic
Camera glass material	sapphir glass

sensor size	1/3 inch CCD or CMOS
camera led light	12PCS white LEDS or IR light, Leds adjustable
Cable length	20/30/50/100 meters, (up to 300m available)
Panning camera system	360 degree rotative camera
Underwater Camera system	rotative camera

Arduino Mega2560:

Arduino MEGA 2560



CE

Product Overview

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560 (datasheet). It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Mega is compatible with most shields designed for the Arduino Duemilanove or Diecimila.

Index

RS radiospares RADIONICS

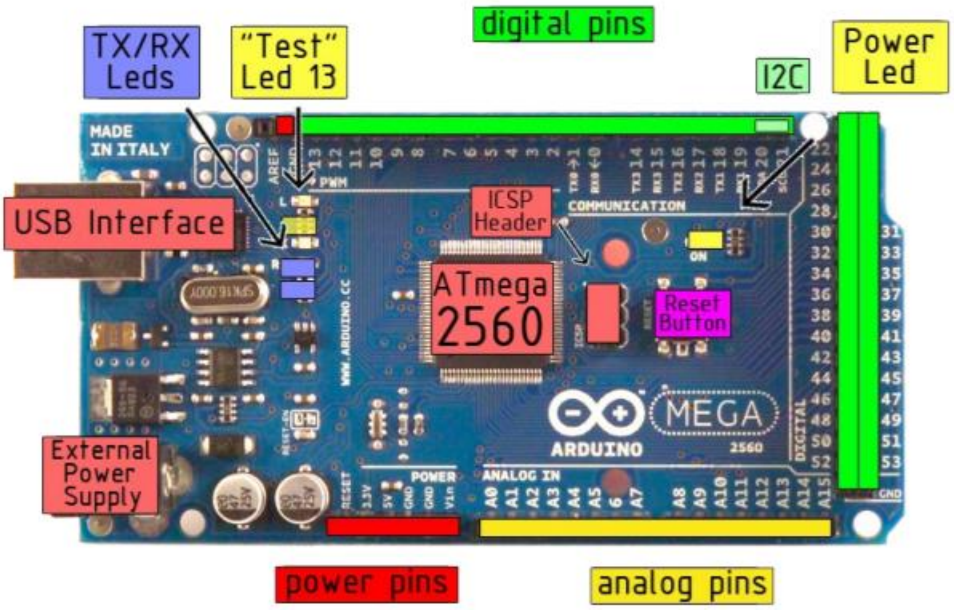
Technical Specification

EAGLE files: arduino-mega2560-reference-design.zip Schematic: arduino-mega2560-schematic.pdf

Summary

Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	54 (of which 14 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB used by bootloader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz

the board



Power

The Arduino Mega2560 can be powered via the USB connection or with an external power supply. The power source is selected automatically. External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The Mega2560 differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega8U2 programmed as a USB-to-serial converter.

The power pins are as follows:

- **VIN.** The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.
- **5V.** The regulated power supply used to power the microcontroller and other components on the board. This can come either from VIN via an on-board regulator, or be supplied by USB or another regulated 5V supply.
- **3V3.** A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.
- **GND.** Ground pins.

Memory

The ATmega2560 has 256 KB of flash memory for storing code (of which 8 KB is used for the bootloader), 8 KB of SRAM and 4 KB of EEPROM (which can be read and written with the EEPROM library).

Input and Output

Each of the 54 digital pins on the Mega can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. In addition, some pins have specialized functions:

- **Serial: 0 (RX) and 1 (TX); Serial 1: 19 (RX) and 18 (TX); Serial 2: 17 (RX) and 16 (TX); Serial 3: 15 (RX) and 14 (TX).** Used to receive (RX) and transmit (TX) TTL serial data. Pins 0 and 1 are also connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip .
- **External Interrupts: 2 (interrupt 0), 3 (interrupt 1), 18 (interrupt 5), 19 (interrupt 4), 20 (interrupt 3), and 21 (interrupt 2).** These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attachInterrupt() function for details.
- **PWM: 0 to 13.** Provide 8-bit PWM output with the analogWrite() function.
- **SPI: 50 (MISO), 51 (MOSI), 52 (SCK), 53 (SS).** These pins support SPI communication, which, although provided by the underlying hardware, is not currently included in the Arduino language. The SPI pins are also broken out on the ICSP header, which is physically compatible with the Duemilanove and Diecimila.
- **LED: 13.** There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.
- **I²C: 20 (SDA) and 21 (SCL).** Support I²C (TWI) communication using the Wire library (documentation on the Wiring website). Note that these pins are not in the same location as the I²C pins on the Duemilanove.

The Mega2560 has 16 analog inputs, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and analogReference() function.

There are a couple of other pins on the board:

- **AREF.** Reference voltage for the analog inputs. Used with analogReference().
- **Reset.** Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

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Communication

The Arduino Mega2560 has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega2560 provides four hardware UARTs for TTL (5V) serial communication. An ATmega8U2 on the board channels one of these over USB and provides a virtual com port to software on the computer (Windows machines will need a .inf file, but OSX and Linux machines will recognize the board as a COM port automatically. The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the board. The RX and TX LEDs on the board will flash when data is being transmitted via the ATmega8U2 chip and USB connection to the computer (but not for serial communication on pins 0 and 1).

A SoftwareSerial library allows for serial communication on any of the Mega's digital pins.

The ATmega2560 also supports I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus; see the documentation on the Wiring website for details. To use the SPI communication, please see the ATmega2560 datasheet.

Programming

The Arduino Mega2560 can be programmed with the Arduino software (download). For details, see the reference and tutorials.

The Atmega2560 on the Arduino Mega comes preburned with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference, C header files).

You can also bypass the bootloader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header; see these instructions for details.

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Automatic (Software) Reset

Rather then requiring a physical press of the reset button before an upload, the Arduino Mega2560 is designed in a way that allows it to be reset by software running on a connected computer. One of the hardware flow control lines (DTR) of the ATmega8U2 is connected to the reset line of the ATmega2560 via a 100 nanofarad capacitor. When this line is asserted (taken low), the reset line drops long enough to reset the chip. The Arduino software uses this capability to allow you to upload code by simply pressing the upload button in the Arduino environment. This means that the bootloader can have a shorter timeout, as the lowering of DTR can be well-coordinated with the start of the upload.

This setup has other implications. When the Mega2560 is connected to either a computer running Mac OS X or Linux, it resets each time a connection is made to it from software (via USB). For the following half-second or so, the bootloader is running on the Mega2560. While it is programmed to ignore malformed data (i.e. anything besides an upload of new code), it will intercept the first few bytes of data sent to the board after a connection is opened. If a sketch running on the board receives one-time configuration or other data when it first starts, make sure that the software with which it communicates waits a second after opening the connection and before sending this data.

The Mega contains a trace that can be cut to disable the auto-reset. The pads on either side of the trace can be soldered together to re-enable it. It's labeled "RESET-EN". You may also be able to disable the auto-reset by connecting a 110 ohm resistor from 5V to the reset line; see this forum thread for details.

USB Overcurrent Protection

The Arduino Mega has a resettable polyfuse that protects your computer's USB ports from shorts and overcurrent. Although most computers provide their own internal protection, the fuse provides an extra layer of protection. If more than 500 mA is applied to the USB port, the fuse will automatically break the connection until the short or overload is removed.

Physical Characteristics and Shield Compatibility

The maximum length and width of the Mega PCB are 4 and 2.1 inches respectively, with the USB connector and power jack extending beyond the former dimension. Three screw holes allow the board to be attached to a surface or case. Note that the distance between digital pins 7 and 8 is 160 mil (0.16"), not an even multiple of the 100 mil spacing of the other pins.

The Mega is designed to be compatible with most shields designed for the Diecimila or Duemilanove. Digital pins 0 to 13 (and the adjacent AREF and GND pins), analog inputs 0 to 5, the power header, and ICSP header are all in equivalent locations. Further the main UART (serial port) is located on the same pins (0 and 1), as are external interrupts 0 and 1 (pins 2 and 3 respectively). SPI is available through the ICSP header on both the Mega and Duemilanove / Diecimila. **Please note that I²C is not located on the same pins on the Mega (20 and 21) as the Duemilanove / Diecimila (analog inputs 4 and 5).**

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How to use Arduino

Arduino can sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling lights, motors, and other actuators. The microcontroller on the board is programmed using the Arduino programming language (based on Wiring) and the Arduino development environment (based on Processing). Arduino projects can be stand-alone or they can communicate with software on running on a computer (e.g. Flash, Processing, MaxMSP).

Arduino is a cross-platoform program. You'll have to follow different instructions for your personal OS. Check on the Arduino site for the latest instructions. *http://arduino.cc/en/Guide/HomePage*

Linux Install **Windows Install** **Mac Install**

Once you have downloaded/unzipped the arduino IDE, you can Plug the Arduino to your PC via USB cable.

Blink led

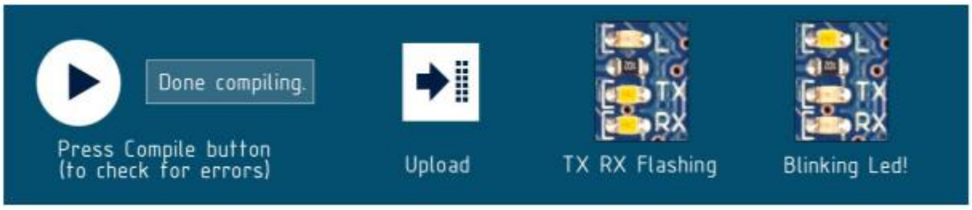
Now you're actually ready to "burn" your first program on the arduino board. To select "blink led", the physical translation of the well known programming "hello world", select

**File>Sketchbook>
Arduino-0017>Examples>
Digital>Blink**

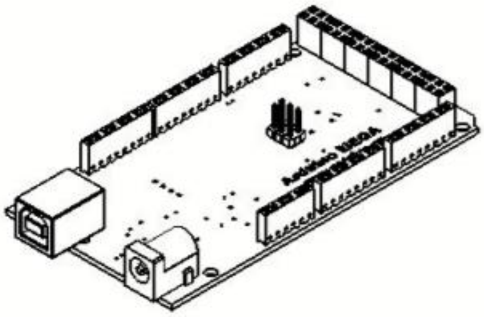
Once you have your skecth you'll see something very close to the screenshot on the right.

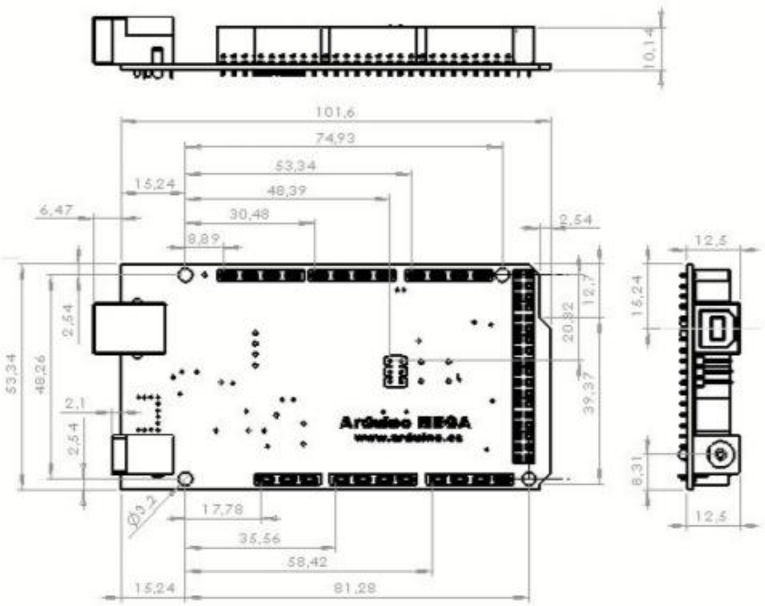
In **Tools>Board** select MEGA

Now you have to go to
Tools>SerialPort
and select the right serial port, the one arduino is attached to.



Dimensioned Drawing





Terms & Conditions

1. Warranties

1.1 The producer warrants that its products will conform to the Specifications. This warranty lasts for one (1) years from the date of the sale. The producer shall not be liable for any defects that are caused by neglect, misuse or mistreatment by the Customer, including improper installation or testing, or for any products that have been altered or modified in any way by a Customer. Moreover, The producer shall not be liable for any defects that result from Customer's design, specifications or instructions for such products. Testing and other quality control techniques are used to the extent the producer deems necessary.

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Enviromental Policies

The producer of Arduino™ has joined the Impatto Zero® policy of LifeGate.it. For each Arduino board produced is created / looked after half squared Km of Costa Rica's forest's.

Power Distribution Board (PDB):

Matek Systems

MANUAL

PDB-XT60 w/ BEC 5V & 12V

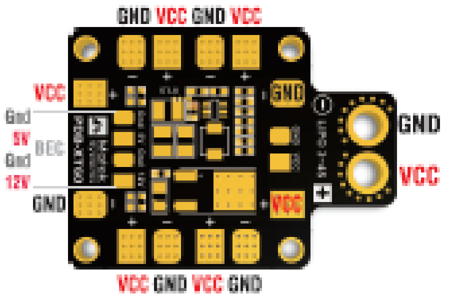
SKU: PDB-XT60

The PDB-XT60 has been engineered to provide the highest possible performance and reliability in a 36*50mm & 4 layers PCB. It distributes power from a LiPo pack to 6 ESCs, as well as providing synchronised & regulated DC 5V outputs & linear regulated DC 12V for powering Cameras, Servos, RC receiver, Flight Controllers, Video Transmitters, LEDs, etc.
It offers a XT60 socket to connect the LiPo pack conveniently.

Features

- 2oz copper, 4-layers &1.6mm PCB.
- Built-in XT60 Socket
- Total 6 pairs ESC solder tabs are fit for H or X type frame
- 5V & 12V Output LED indicators & Short circuit tolerant

Layout



VCC=Battery Voltage

Specifications

General:
- Input voltage range (3S-4S LiPo operation): 9 - 18V DC
- Regulated 5V and 12V outputs
- LED power indications (5V & 12V outputs)
- 6 ESC outputs & 1 pair VCC/GND pads

ESC outputs:
- Continuous current: 25A*4 or 15A*6
- Peak current (10 seconds/minute): 30A*4 or 20A*6

BEC 5V output:
- Designed for RC Receivers, Flight controllers, OSD, and Servos.
- DC/DC synchronous buck regulator.
- Voltage: 5.0 +/- 0.1VDC
- Continuous current: 2 Amps (Max.2.5A 10s/minute)
- Output Ripple: 40mV (Vin=16V, VOut=5V@2A load)
- Short-circuit tolerant (5 seconds/minute)

BEC 12V output:
- Designed for Video TX or FPV camera with linear regulator.
- The battery should be 4S LiPo (13~18V DC)
- Voltage: 12.0 +/- 0.3VDC
- Continuous current: 500mA (Max.0.8A 5s/minute)
- Short-circuit tolerant (2 seconds/minute)

BEC 12V @ 3S LiPo
- Output voltage= 3S LiPo voltage -1V

Physical:
- Dimensions: 36 x 50 x 4 mm (without XT60)
- Mounting: 30.5 x 30.5mm, Φ3mm
- Weight: 7.5g(w/o XT60), 11g(w/ XT60)

Connections